THE Water Research FOUNDATION

PROJECT NO.
SENG6R16/4835

Designing Sensor Networks and Locations on an Urban Sewershed Scale

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Abstract and Benefits

Abstract:

This research project examines the current state of remote monitoring technology applications in urban sewersheds, including the greatest challenges facing wastewater and combined wastewater and stormwater systems. Information was collected from utilities and technology providers through an online survey, case studies, and an expert workshop. The main challenges utilities faced for managing urban sewersheds were identified (capacity, inflow and infiltration, aging infrastructure, compliance) and the use of sensors in a sewershed network was found to be in its infancy.

Benefits:

- Identifies reliable advanced sensing technologies and networks within sewersheds, and their implementation issues, to allow utilities to understand costs and benefits associated with using sensing technologies.
- Identifies opportunities to implement real-time sensor networks to guide decision making for system operation and capital planning.
- Defers capital upgrades by real-time operation and management of collection system flows within the sewershed.
- Provides better targeting of remediation activities to reduce industrial, commercial, and wet weather overflows.
- Increases capability to manage regulatory requirements for pollutant release and overflow control.
- Establishes a framework to introduce end-to-end, real-time system control and management for indirect potable reuse.

Keywords: Sewershed, sensors, technology, wastewater, stormwater, case studies.

Contents

Acronyms and Abbreviations

API	Application programming interface
APM	Asset performance management
AOC	Assimilable organic carbon
AVFM	Area velocity flow meter
BOD	Biological oxygen demand
BTX	Benzene, toluene, and xylene
CAD	Computer-aided design
CCTV	Closed-circuit television
COD	Chemical oxidation demand
CSO	Combined sewer overflow
DMA	District metering areas
DO	Dissolved oxygen
FOG	Fats, oils, and grease
GIS	Geographical information system
GPRS	General packet radio service
GSM	Global system for mobile communication
H_2S	Hydrogen sulfide
HMI	Human machine interface
I&I	Inflow and infiltration
IEEE	Institute **of** Electrical **and** Electronics Engineers
IoT	Internet of Things
IP	Internet protocol
IT	Information technology
km	Kilometer
mA	Milliamperes
MGD	Million gallons per day
MHz	Megahertz
MSDGC	Metropolitan Sewer District of Greater Cincinnati
N/A	Not applicable
NB-IoT	NarrowBand-Internet of Things
NH_4	Ammonia
NO_2	Nitrite
NO_3	Nitrate
NPDES	National Pollutant Discharge Elimination System
NRW	Non-revenue water

O&M	Operation and maintenance
ORP	Oxygen reduction potential
PLC	Programmable logic controller
ppm	Parts per million
QA/QC	Quality assurance/quality control
RT-DSS	Real-Time Control and Decision Support System
SCADA	Supervisory control and data acquisition
SPU	Seattle Public Utilities
SSO	Sanitary sewer overflow
SWAN	Smart Water Networks Forum
TOC	Total organic carbon
TSS	Total suspended solids
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV	Ultraviolet
VOC	Volatile organic compounds
WLAN	Wireless local area network
WRF	The Water Research Foundation
WRRF	Water resource recovery facility
WWTP	Wastewater treatment plant

Executive Summary

Many utilities operating sanitary sewer and combined storm sewer systems are faced with water quality and quantity challenges related to collection system management. These challenges are primarily related to the control of industrial/commercial wastewater inflows and wet weather flows that affect the viability of treatment and water reuse operations and the frequency/pollutant loading into the environment from system overflows. With the recent emergence of low-cost, reliable water quality and quantity sensors and the exponential increases in computing power, the promise of real-time monitoring and operation of collection systems to address these challenges is being realized. Because utilities must comply with water quality control and overflow reduction requirements, sensor-based networks on a sewershed scale for real-time decision-making and operation can optimize collection system performance before investing in major, capital-intensive projects.

The objective of this project was to research the current and future states of the use of advanced sensors (i.e., sensors that monitor, collect, and transfer measurements in near real-time and can be remotely deployed) in urban sewersheds to solve critical problems for the industry. This research included identifying innovative system applications and outcomes that have taken place within the water industry.

The Project Team designed an online survey for and conducted interviews with wastewater and technology partners to yield quantifiable indicators of the current and future states. A review of the survey results, discussions occurring during an expert workshop, and case studies identified the top challenges as capacity issues, inflow and infiltration (I&I), asset management, pump station upgrades and improvements, combined sewer overflows (CSOs), and aging infrastructure.

These challenges, which are not listed in any particular order, provide insight into the most pressing issues wastewater and stormwater utilities face. Sensors are commercially available for use in sewershed networks (i.e., at the water resource recovery facilities [WRRFs], in receiving waters, and in the sewershed). These sensors measure flow, level, and water quality parameters. However, wastewater utilities tend to use few of the available options for monitoring in their sewersheds, with most utilities monitoring water quality parameters only at the WRRF. Measuring these parameters in the sewershed is considered too expensive to justify, with the instrumentation thought to be unreliable in the wastewater environment. This reasoning indicates that monitoring in an urban sewershed network is in its infancy and has significant potential for growth.

The use of sensors not only at WRRFs, but also in receiving waters and in sewersheds, can help reduce capacity issues, I&I, and CSOs, and assist in asset management and identification of aging infrastructure within the network. However, many utilities and solution providers surveyed reported that the sensors are unreliable, too expensive to justify their use, or there is no need.

Most utilities surveyed were found to use multiple hydraulic models. Sensors can validate model calibrations, support model refinement, and specify adjustments to model assumptions. Using sensors in the sewershed can strengthen model results, provide real-time information, and address the challenges identified by wastewater utilities and technology providers.

Based on the results of the surveys, case studies provided, and the expert workshop, four use cases have been identified as follows:

- **Use Case No. 1:** Managing dry weather (sanitary sewer overflow [SSO]) and wet weather (CSO) overflows through data correlation and enhanced operational practices.

- **Use Case No. 2:** Developing video analytics for different types of pipeline materials to rapidly identify problems that lead to I&I, while reducing the cost and human error associated with reviewing closed-circuit television (CCTV) video.
- **Use Case No. 3:** Evaluating water quality within the sewer, and using the results in decision-making to reduce the environmental impact of CSOs.
- **Use Case No. 4:** Monitoring for conditions that might cause pipe corrosion (e.g., H_2S levels) and optimize chemical feed based on sulfide production potential.

It is recommended that the Phase II Demonstration project include two of these use cases.

This final report includes a description of the approach for the project, a summary of the findings, and technical memorandums for each of the associated tasks (Appendices A through E).

CHAPTER 1

Task 1 – Survey Wastewater Utilities and Technology Companies

The Project Team designed a survey to determine the current state of the use of advanced sensor networks (i.e., networks of sensors that monitor, collect, and transfer measurements in near real-time and can be remotely deployed) in sewersheds. The survey focused on identifying major challenges facing the industry and use cases in advanced sewershed monitoring programs addressing these challenges. The survey was administered online to forty leading wastewater utilities and technology companies, and results were collected and analyzed by the Project Team.

The survey questions for the utilities were divided into the following topics:

- Utility information (5 questions)
- Regulatory environment (2 questions)
- Challenges (1 question)
- Technology utilization (19 questions)
- Future outlook (3 questions)

The surveys included responses from 20 utilities and 20 technology providers. Summary conclusions for the survey responses are as follows:

- Challenges of greatest concern identified by utilities were capacity issues and inflow and infiltration (I&I).
- Challenges of greatest concern to utilities, as observed by technology providers, were capacity issues and combined sewer overflows (CSOs).
- Wastewater utilities typically measure only water quality at the water resource recovery facility (WRRF), with some measuring water quality in the collection system, and fewer measuring water quality in the receiving streams.
- The main reasons utilities provided for not measuring parameters of interest were that the sensors are considered too expensive to justify and are unreliable in the wastewater environment.
- Utilities often use more than one hydraulic model.

The majority of utilities surveyed expressed interest in learning more about the application of advanced technologies for use in the sewershed, such as real-time monitoring using sensors, predictive analytics, decision-support systems, and automated control.

The administered survey and detailed analysis of the results can be found in Appendix A.

Task 1 also included gathering case studies. To support this approach, those utilities and technology providers that responded to the industry survey distributed in Task 1 were separately requested to provide a documented case study that they felt could be educational for other utilities.

Case studies were received from six wastewater utilities and four technology providers. Based on the survey results, which indicated that advanced monitoring programs in the sewershed are not common, the small number of case studies received was not surprising. The case studies received involved sewersheds of various sizes and complexities representing a good cross-section of the industry.

Monitoring of sewershed was generally seen as useful to support other utility goals such as system optimization or reduction in capital expenditures. Monitoring was also used to support the resolution of imposed actions such as consent decrees.

The case studies supported the survey results, which indicated that currently very few parameters are typically monitored, with level and flow being the predominant parameters. Monitoring water quality and other similar parameters is rarely used in the sewershed.

The majority of case studies involved the use of a small number of sensors located in specific areas of interest, such as a part of the system with previous problems that required minimal analytics and visualization to resolve the problems. Case studies that aimed at managing the entire system involved complex analytics and visualization of the entire sewershed.

The details of the case studies received and an analysis of these appears in Appendix B.

CHAPTER 2

Task 2 – Assemble Panel and Conduct Expert Workshop

Using the results from Task 1, the Project Team assembled a group of industry experts from leading wastewater utilities and technology companies and conducted a one-day workshop. The purpose of the workshop was to review and build on the findings of the survey to identify the top industry sewershed challenges and potential use cases to address them. The consultant for the Water Research Foundation (WRF) Big Data research project (SENG7R16) was also invited to participate in the Expert Workshop.

Attendees at the workshop included representatives from six utilities and eight technology providers. These representatives participated in breakout sessions where they were separated into two groups.

The first group's top five use cases were as follows:

1. Correlation between weather events and operational data to overflow events.
2. Driving more efficient asset management/failure prediction.
3. Identification/prediction of nitrification within chloraminated systems and non-revenue water (NRW).
4. Real-time modeling driven by real-time sensor data.
5. Advanced analytics for source water protection.

The second group's top five use cases were these:

1. Dynamic silt monitoring/estimation.
2. Sensor placement optimization.
3. Sanitary Sewer Overflow (SSO) mitigation – simple level sensor.
4. NRW – District metered area.
5. Managing river/surface water quality.

A detailed summary of the expert workshop appears in Appendix C.

CHAPTER 3

Task 3 – Identify Available Sensor Technologies

The Project Team built on prior research conducted by WRF, the United States Environmental Protection Agency (U.S. EPA), and others to identify different groups of sensors available for use in urban sewershed networks. The suite of sensors commercially available extended beyond water quality to include other types such as flow, level, and weather sensors. Information collected during this task was incorporated in Task 4 for use case development.

Although sensor technologies are available for monitoring urban sewersheds, the sensor review found that many utilities monitor at the WRRFs or pump stations and not necessarily in the sewershed. What was apparent during the various investigations for this task is that the industry is still very much in its infancy with regard to urban sewershed monitoring that extends beyond the WRRFs and pump stations.

During the review of available technologies, technology providers were found that are receptive to utility feedback and have begun providing support for water recycling and reuse.

A summary of the available sensor technologies appears in Appendix D.

CHAPTER 4

Task 4 – Develop Use Cases

Information gained during Tasks 1 through 3 was used to develop use cases that address the most significant challenges for implementation of advanced sensor networks in urban sewersheds. These use cases were a combination of successful case studies that have been implemented by utilities and new use cases that can be considered for a Phase II project.

Survey results and case studies provided by utilities and technology providers, along with information from the expert workshop, were reviewed to summarize the challenges identified. Based on these challenges, the following four use cases were developed for potential inclusion in the Phase II project:

- **Use Case No. 1:** Managing dry weather (SSO) and wet weather (CSO) overflows through data correlation and enhanced operational practices.
- **Use Case No. 2:** Developing video analytics for different types of pipeline materials to rapidly identify problems that lead to I&I, while reducing the cost and human error associated with reviewing closed-circuit television (CCTV) video.
- **Use Case No. 3:** Evaluating water quality within the sewer, and using the results in decision making to reduce the environmental impact of CSOs.
- **Use Case No. 4:** Monitoring for conditions that might cause pipe corrosion (e.g., H_2S levels) and optimize chemical feed based on sulfide production potential.

Details of the use cases developed and the approach to selection of the final four use cases appear in Appendix E.

CHAPTER 5

Conclusions

Based on the survey results, case studies received, and outcomes of the expert workshop, the following conclusions were drawn:

- Acceptance of advanced sensor technology and big data analytics will require a cultural shift in the wastewater industry.
- Opportunities to share knowledge among utilities about work already completed in the application of advanced sensor technology and big data analytics have not been successfully utilized.
- The use of sensor technology in sewersheds is in its infancy. Typically, wastewater utilities measure more parameters at the WRRF (e.g., water quality parameters) and deploy very few sensors in the sewershed.
- The parameters most typically monitored in the sewershed are flow and level.
- The main challenges for the wastewater industry include capacity issues, aging infrastructure, and asset management.
- Most technology solutions attempt to solve a single, isolated problem rather than consider the holistic sewershed system. This can lead to solutions that tend to move a problem around the system rather than solving the actual problem.
- It is considered to be difficult to predict the return on investment for technology applications in the sewershed. Some utilities have been able to calculate savings based on measurable results, which may be useful as a benchmark.
  - Ideally, the solution should be linked to a known monetary cost (regulatory fines, reduction of labor).
  - The capital cost of implementing technology-based solutions, such as extensive monitoring programs, can be much greater than the “tried and true” approaches previously used, and the predicted savings can be difficult to quantify. Utilities need to include full life-cycle costs of activities over a reasonable period (e.g., five years) to determine actual costs and savings.

APPENDIX A

Task 1 – Survey Wastewater Utilities and Technology Companies – Summary of Survey Results

Designing Sensor Networks and Locations on an Urban Sewershed Scale

Task 1 – Survey Wastewater Utilities and Technology Companies – Summary of Survey Results

PREPARED FOR:	Water Environment & Research Foundation
PREPARED BY:	CH2M
DATE:	May 11, 2018
PROJECT NUMBER:	SENG6R16

The plan for *Task 1 – Survey Wastewater Utilities and Technology Companies* of project SENG6R16 involved design of a survey to determine the current state of the use of advanced sensor networks in sewersheds. The survey focused on identifying major challenges facing the industry and use cases in advanced sewershed monitoring programs addressing these challenges. The survey was administered online by The Smart Water Networks Forum (SWAN) Forum using the tool Survey Gizmo. This Technical Memorandum provides a summary of the process and results of the survey.

Approach

Initially a single set of survey questions was developed to gather information about the current state of the use of advanced sensor networks in sewersheds and the major challenges facing the industry. These questions targeted wastewater utilities and are presented in Attachment A.

The survey questions for the utilities were divided into the following topics:

- Utility information (5 questions)
- Regulatory environment (2 questions)
- Challenges (1 question)
- Technology utilization (19 questions)
- Future outlook (3 questions)

A second set of survey questions was developed for technology providers to gain insight from technology providers. This survey tailored the questions to the technology provider perspective and included additional questions about the future of related technologies. The survey questions for technology providers are presented in Attachment B.

The survey questions for the technology providers were divided into the following topics:

- Introductory information (4 questions)
- Regulatory environment (2 questions)

- Challenges (1 question)
- Technology utilization (16 questions)
- Future outlook (4 questions)

The details and analysis of the survey results are presented in this document and organized by the survey topics.

A list of wastewater utilities and technology providers was generated from CH2M, WE&RF, and SWAN contacts. Those on the list were asked to provide guidance for additional organizations to be contacted to take the survey.

The WE&RF Project Steering Committee reviewed and provided comments on the survey questions and potential list of respondents. The comments were incorporated prior to administering the survey.

Survey Results

Discussion of the survey results is organized by the survey topics.

Introductory Information

General information was sought from the utilities participating in the survey including name, location, city, and country. Of the 20 respondents, 16 were based in the United States, representing nine states, with two respondents from Europe, one from South America, and one from Southeast Asia. Twenty solution providers participated in the survey.

The introductory information results are presented and discussed using a general form of the questions in this section.

Is your utility a public or a private entity?

Utilities were asked whether they were public or private entities. Sixteen of the 20 respondents where public entities and four were private entities.

What technologies does your organization supply to water and wastewater utilities?

Technology providers were asked to identify all types of technologies provided to the water/wastewater sector. The majority were providers of multiple technologies rather than specializing in a single area as shown in Figure 1. The “Other” category incorporated more specialized technologies, such as armatures, asset management, or maintenance optimization software.

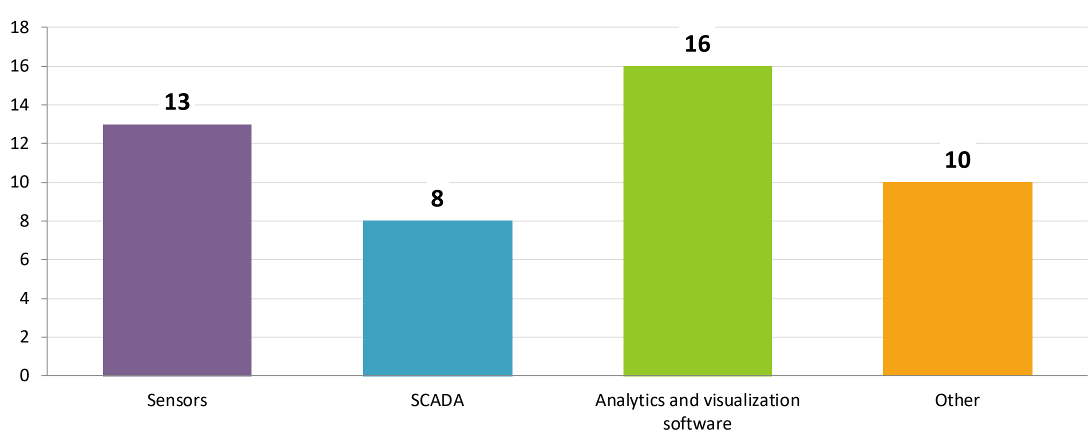


Figure 1. Primary Technologies Provided by Survey Respondents.

What types of facilities are managed?

Both utilities and technology providers were asked this question. The intent was to identify utilities that may specialize only in wastewater and technology providers that supply only to wastewater utilities. The results presented in Figure 2 indicate that technology providers generally supply all parts of the water sector, and most utilities are not solely wastewater utilities.

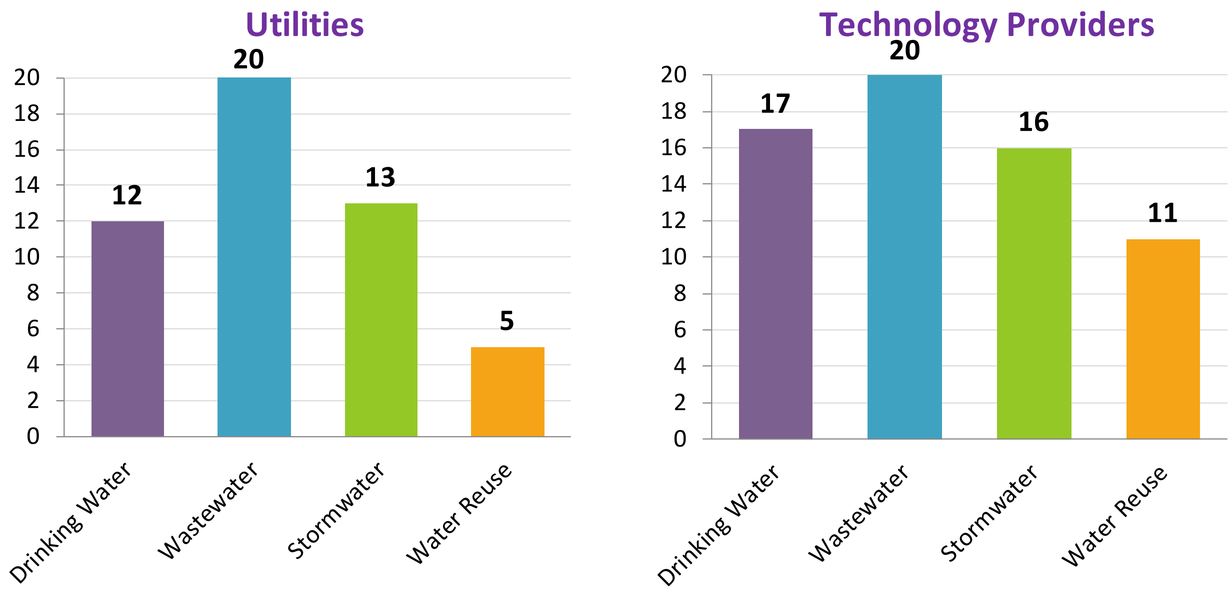


Figure 2. Facility Types Managed.

Of the 20 utility respondents, all manage wastewater facilities. A further breakdown of facilities managed by respondents is as follows:

- Four manage wastewater only
- One manages wastewater, drinking water, stormwater, and reuse
- Eight manage wastewater, drinking water, and stormwater
- One manages wastewater, drinking water, and reuse
- Three manage wastewater, stormwater, and reuse
- Two manage wastewater and drinking water
- One manages wastewater and stormwater

Of the 20 solution providers who responded, all supplied to wastewater facilities. A further breakdown of solutions by facility type is as follows:

- One supplies to wastewater only
- 10 supply to wastewater, drinking water, stormwater, and reuse
- Four supply to wastewater, drinking water, and stormwater
- One supplies to wastewater, drinking water, and reuse
- None supply to wastewater, stormwater, and reuse
- Two supply to wastewater and drinking water
- Two supply to wastewater and stormwater

What population does your utility serve?

The population served for the responding utilities varied, with most serving large utilities as shown in Figure 3. Twelve (60%) of the responding utilities serve populations of 1,000,000 or more, of which four are private and eight are public utilities.

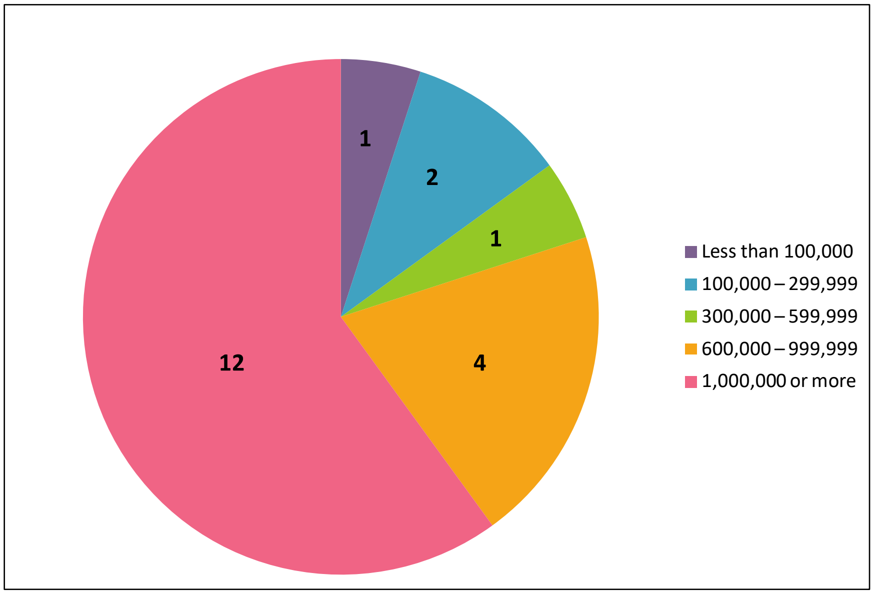


Figure 3. Population Served by Responding Utilities.

What types of sewer collection systems (sewershed network) are managed?

Utilities were asked what types of collection systems they manage, and technology providers were asked what their customers typically managed. Results are presented in Figure 4. The “Other” category included cesspool and septic tanks, wastewater drainage systems in buildings, and rainwater harvesting. Of the 20 utilities surveyed, 18 manage separate sewers, with 12 also managing combined sewers.

The breakdown of the sewer collection systems managed by utilities are as follows:

- Five manage combined sewer, separate sewer, and separate stormwater
- Four manage combined sewer and separate sewer
- Six manage separate sewer and separate stormwater
- Two manage combined sewer
- Three manage separate sewer

The breakdown of the sewer collection systems supplied by technology providers are as follows:

- Three supply to combined sewer, separate sewer, separate stormwater, and other
- Thirteen supply to combined sewer, separate sewer, separate stormwater
- Three supply to combined and separate sewer
- One supplies to separate sewer and other

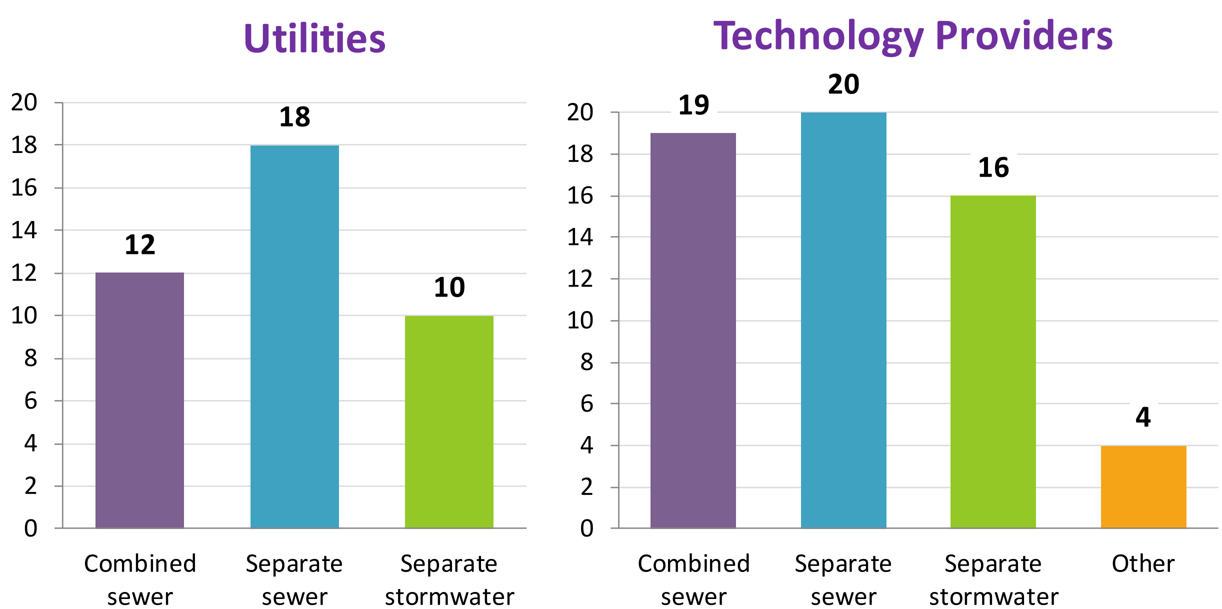


Figure 4. Types of Sewer Collection Systems Managed.

What is the estimated total length of each type of pipeline in the sewershed network?

Utilities were asked the total length of gravity and force main sewers in their respective networks, and technology providers were asked the same about their typical customers. Results ranged from five to 50,000 miles. This result indicates the diversity of the utilities surveyed for this project.

Regulatory Environment

The survey results are presented and discussed using a general form of the survey questions.

Are utilities in the survey required to report to a regulatory authority?

Of the 20 utilities and technology providers to respond, all had requirements for reporting to regulatory authorities as shown in Figure 5.

The category "Other" includes National Pollutant Discharge Elimination System, Sewer System Management Plan, Consent Decree Documents, and Periodic Price Review reporting requirements.

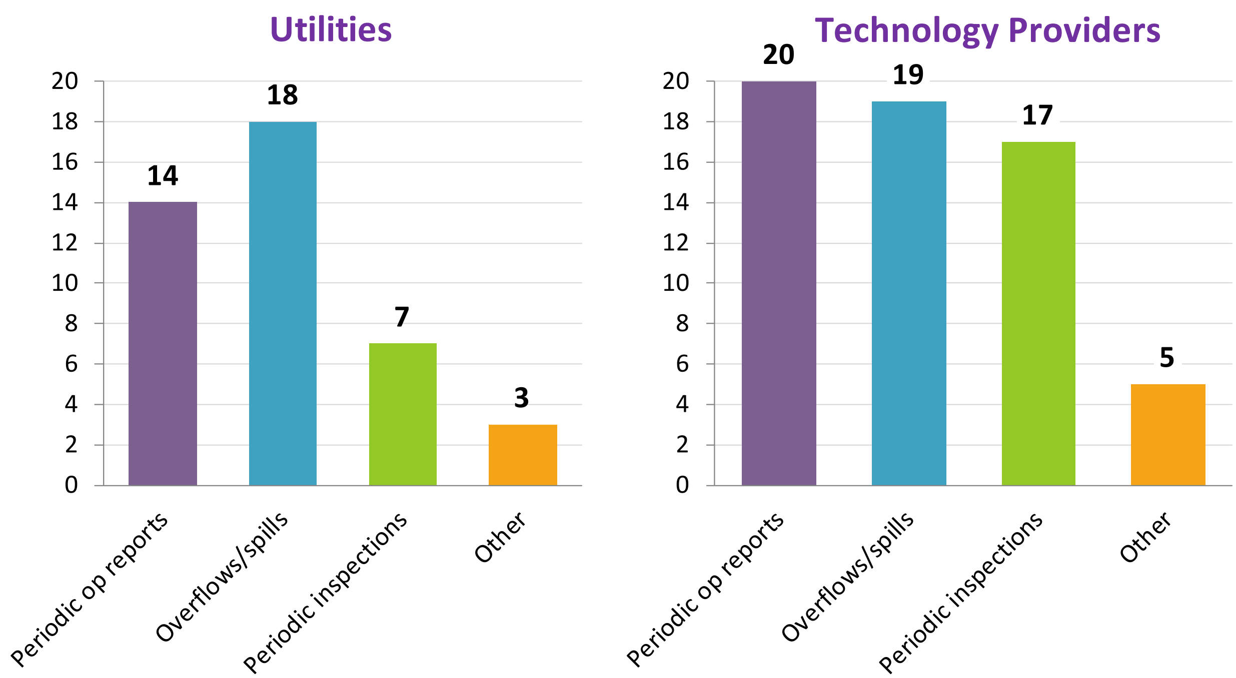


Figure 5. Regulatory Reporting Types.

FOR U.S. UTILITIES: Are utilities in the survey currently under a regulatory agreement such as a Consent Decree or Stipulated Order?

Six of the 16 U.S. utilities responding to the survey were under a Consent Decree or Stipulated Order as shown in Figure 6.

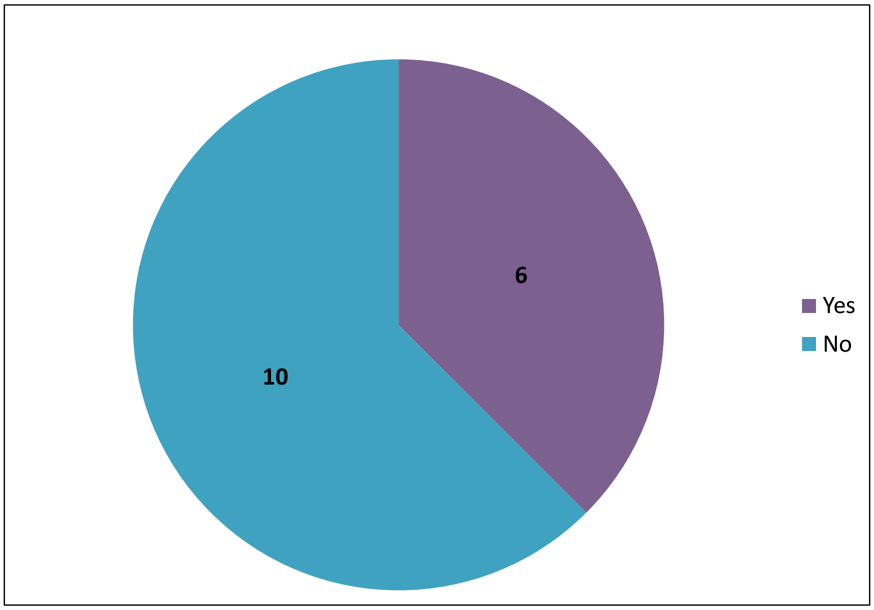


Figure 6. U.S. Utilities Under a Regulatory Agreement.

Challenges

The survey results are presented and discussed using a general form of the survey questions.

What are the main sewershed network challenges/services?

This question asked for a rating of 1 to 5, where 1 = not a challenge to our utility and 5 = challenge that requires immediate attention/solution. The topics to be rated were as follows:

- Aging infrastructure
- Compliance monitoring (regulation)
- Capacity issues (inflow and infiltration)
- Pump (lift) station upgrades/improvements
- Inter-agency conflict/communication
- Combined sewer overflows (CSOs)
- Sanitary sewer overflows (SSOs)
- External flooding and pollution
- Customer flooding
- Asset management
- Other (please specify)

Results obtained using the 1 to 5 rating scale did not provide any definitive results. The ratings were therefore adjusted to a Low/Neutral/High scale where 1 and 2 were combined to be “Low,” 3 was made “Neutral,” and 4 and 5 were combined to be “High.”

Results using the Low/Neutral/High rating scale are presented in Table 1. The cells highlighted in yellow are those representing greater than half of the survey respondents in each group (i.e., greater than 10). The results indicate the following:

- Utilities are concerned about capacity issues and inflow and infiltration (I&I).
- Utilities are not concerned about combined sewer overflows.
- Technology providers to wastewater utilities believe that utilities are concerned about many more issues, including these:
  - Compliance monitoring
  - Capacity issues
  - CSOs
  - SSOs
  - External flooding and pollution
  - Asset management
  - Aging infrastructure

Table 1. Sewershed Network Challenges.

	Utilities			Technology Providers		
	Low	Neutral	High	Low	Neutral	High
Compliance monitoring (regulation)	10	4	6	3	3	14
Capacity issues (inflow and infiltration)	3	4	13	1	2	17
Pump (lift) station upgrades/improvements	1	10	9	1	9	10
Inter-agency conflict/communication	8	5	7	6	8	6
Combined Sewage Overflows (CSOs)	13	2	5	2	3	15
Sanitary Sewage Overflows (SSOs)	9	7	4	2	4	14
External flooding and pollution	7	7	6	0	8	12
Customer flooding	9	4	7	4	10	6
Asset management	1	10	9	1	5	14
Aging infrastructure	-	-	-	2	3	15

Technology Utilization

The survey results are presented and discussed using a general form of the survey questions.

How many pump (lift) stations would be located in the sewershed network?

The number of pump stations in a sewershed is dependent on a number of environmental factors such as terrain and size of the sewershed. The numbers provided ranged from zero to 6,000, indicating the diversity of the utilities responding to the survey.

Is a pump station control system typically used? If so, what type?

This question asked to select all that apply.

- Standalone
- Auto-dialer alarm system (detects pump failure and/or high wet-well levels)
- Annunciator system (global system for mobile communication (GSM)/general packet radio service (GPRS)/3G based)
- Connected to SCADA system
- Relay logic system (tied to float switches)
- Programmable logic controller (PLC) or micro-processor-based
- Intelligent pump station management (provides integrated real-time control of stations)
- Other (please specify):
- N/A

The results presented in Figure 7 indicate that the dominant pump station control systems in use are connected to a supervisory control and data acquisition (SCADA) system or PLCs. Note that all 20 utilities are connected to a SCADA system, although the results below indicate that one utility is not. Based on additional survey responses, it was concluded this omission was in error. Two of the 20 technology providers responded with “Don’t Know” for this question.

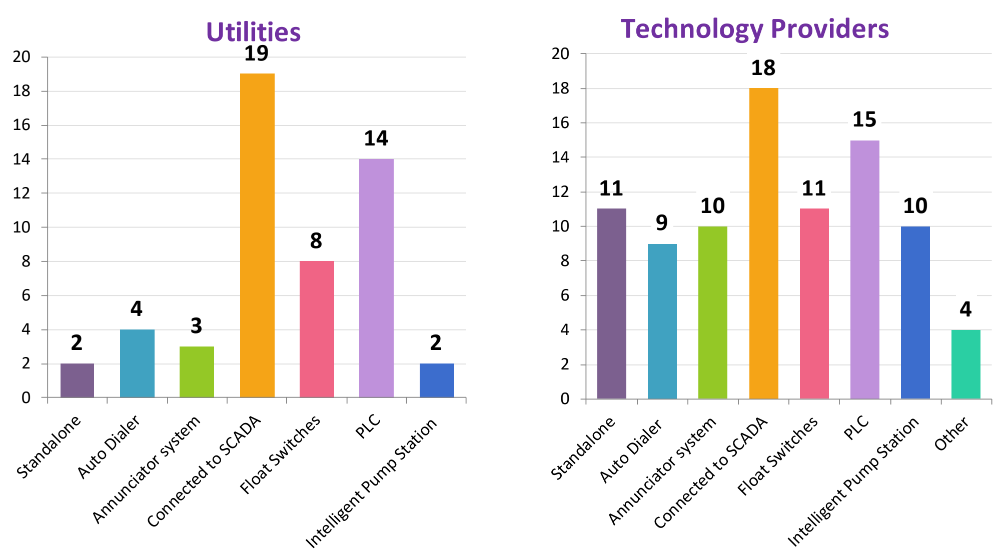


Figure 7. Pump Station Control Systems.

Which online sensors are used to measure water levels or flow in the sewershed network(s)?

This question asked respondents to select all that apply.

- Level sensors
- Flow meters
- Other
- N/A

The survey results are summarized in Figure 8. Based on these results, utilities use flowmeters and level sensors equally to monitor sewersheds. The entry for “Other” included pressure monitors.

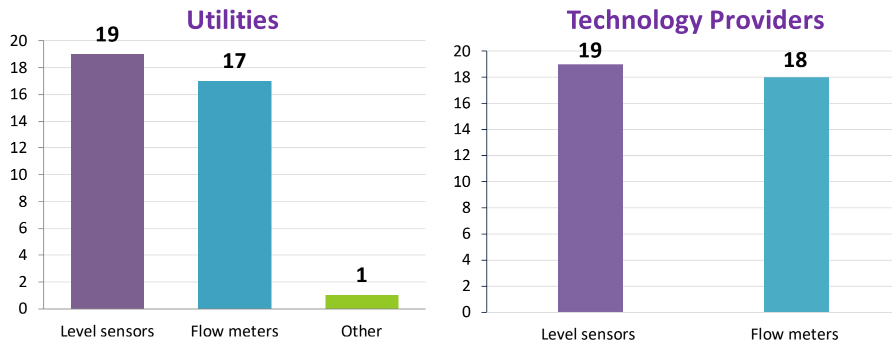


Figure 8. Sensors Used for Flow and Level Monitoring.

Which rain gauge sensors are used to measure and transmit data about current sewershed weather conditions?

This question asked respondents to select all that apply.

- Physical gauges (e.g., tipping bucket)
- Virtual gauges (e.g., radar)
- Other
- N/A

Figure 9 presents the results identifying the rain gauge types used by wastewater utilities. Physical rain gauges are used more often than other options. The term “Other” includes external sources, consultants, and none.

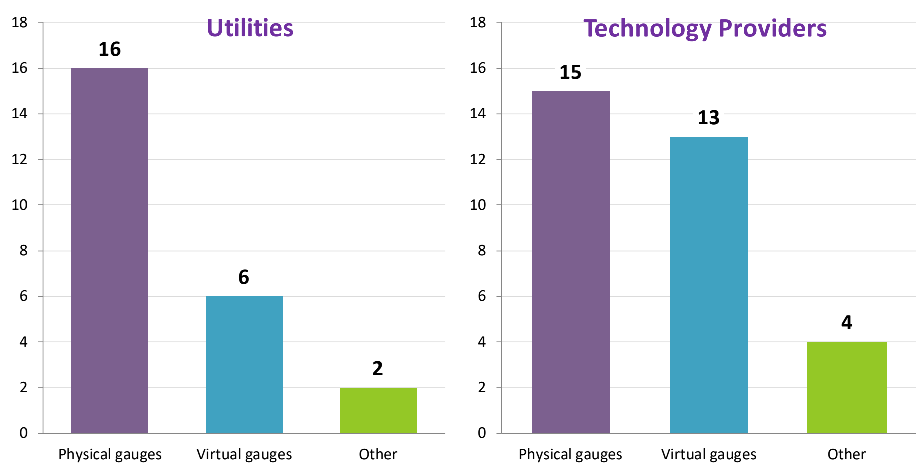


Figure 9. Rain Gauge Sensors Used.

Do these gauges provide historical or real-time weather data?

This question asked respondents to select all that apply.

- Historical
- Real-time
- Batch readings

This question was seeking to determine whether utilities used real-time weather information for operations or collected more historical information. More than half of the utilities in the survey used real-time weather data as shown in Figure 10.

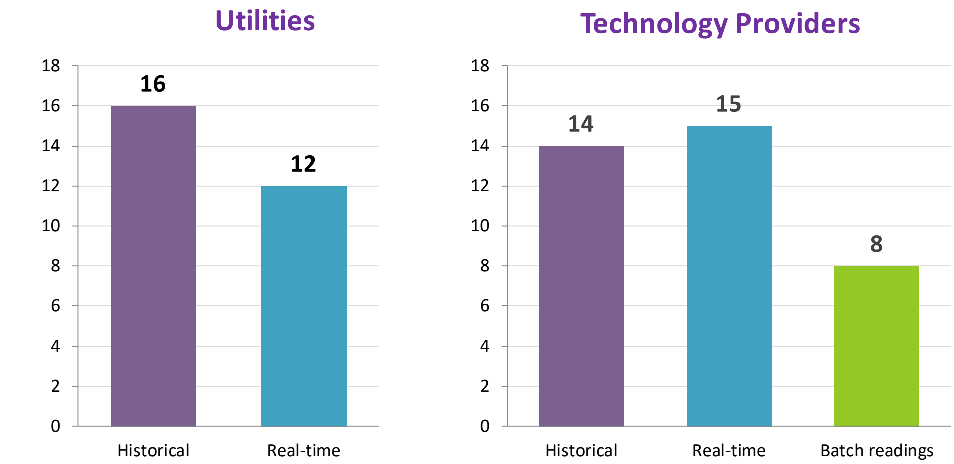


Figure 10. Weather Data Types.

Are online sensors used to measure water quality in the sewershed network(s)?

This question asked respondents to select all that apply.

- At the treatment plant (water resource recovery facility)
- In the sewershed network
- Receiving streams
- N/A

Utilities and technology providers were asked about the use of online water quality monitoring sensors throughout the wastewater system, including at the water resource recovery facility (WRRF), in the collection system, and in receiving waters. The majority of wastewater utilities indicated that they measure water quality at the WRRF, with the fewest measuring it in receiving streams. Technology providers indicated that their clients typically follow the same pattern (Figure 11).

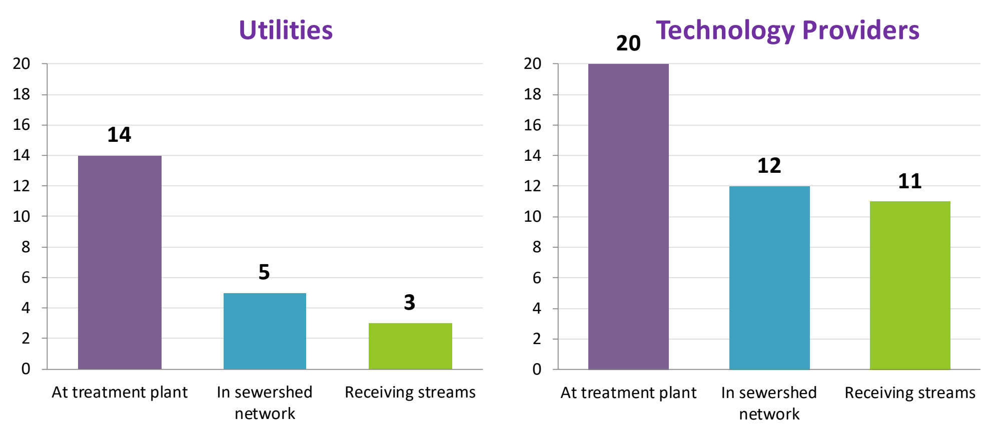


Figure 11. Online Water Quality Monitoring Locations.

Please specify if your company supplies online water quality sensors.

- At the treatment plant (WRRF)
- In the sewershed network
- Receiving streams

In this question, technology providers were asked whether they supplied sensors for use in the locations specified. In a later question, they were asked what parameters their sensors measure. Eleven technology providers responded to these questions with results provided in Figure 12.

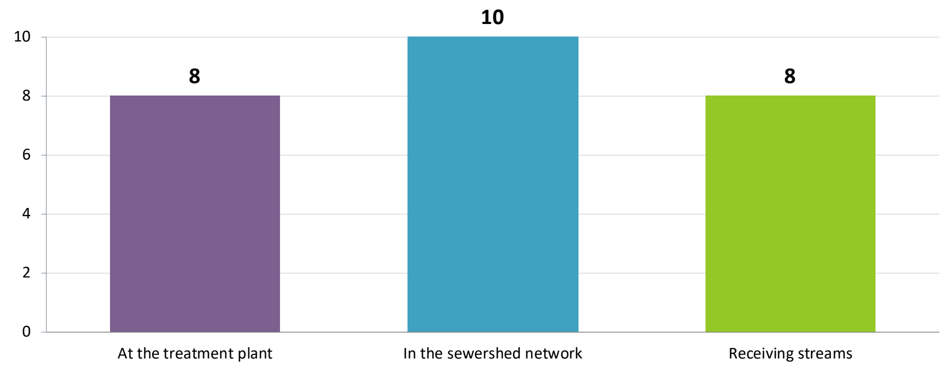


Figure 12. Sensor Locations Supported by Technology Providers.

Please specify which parameters your company measures using online water quality sensors.

Eleven technology providers responded to this question, with the results provided in Figure 13. “Other” included hydrogen sulfide (H_2S), nitrate (NO_3), nitrite (NO_2), ammonia (NH_4), temperature, and turbidity. (The parameter shown as “Organic Spectrum” refers to the use of spectral absorbance in the UV and/or visible ranges to identify organics.)

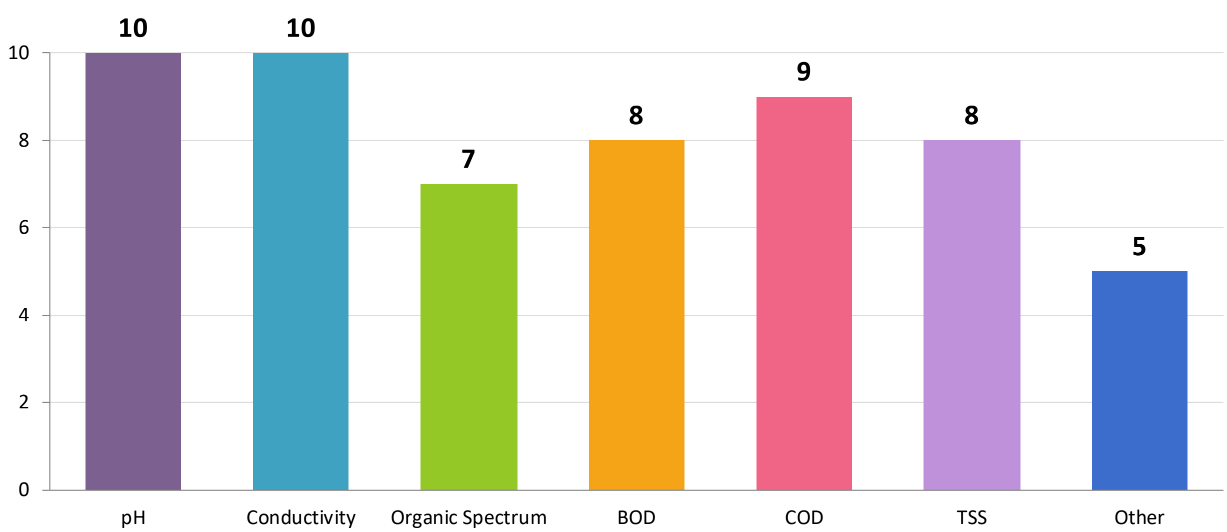


Figure 13. Parameters Measured by Technology Providers.

If online sensors are used to measure water quality in the sewershed network, which parameters are measured?

This question asked respondents to select all that apply.

- pH
- Conductivity
- Organic Spectrum
- Biological Oxygen Demand
- Chemical Oxidation Demand
- Total Suspended Solids
- Other

Nine utilities and 14 technology providers responded to this question. Utilities indicated that pH and conductivity were the most commonly measured water quality parameters, whereas technology providers indicated that biological oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS) were also commonly measured as shown in Figure 14. “Other” included dissolved oxygen (DO), temperature, hydrogen sulfide (H_2S), and volatile organic compounds (VOC) monitoring in the air phase as a proxy for presence of VOC in water.

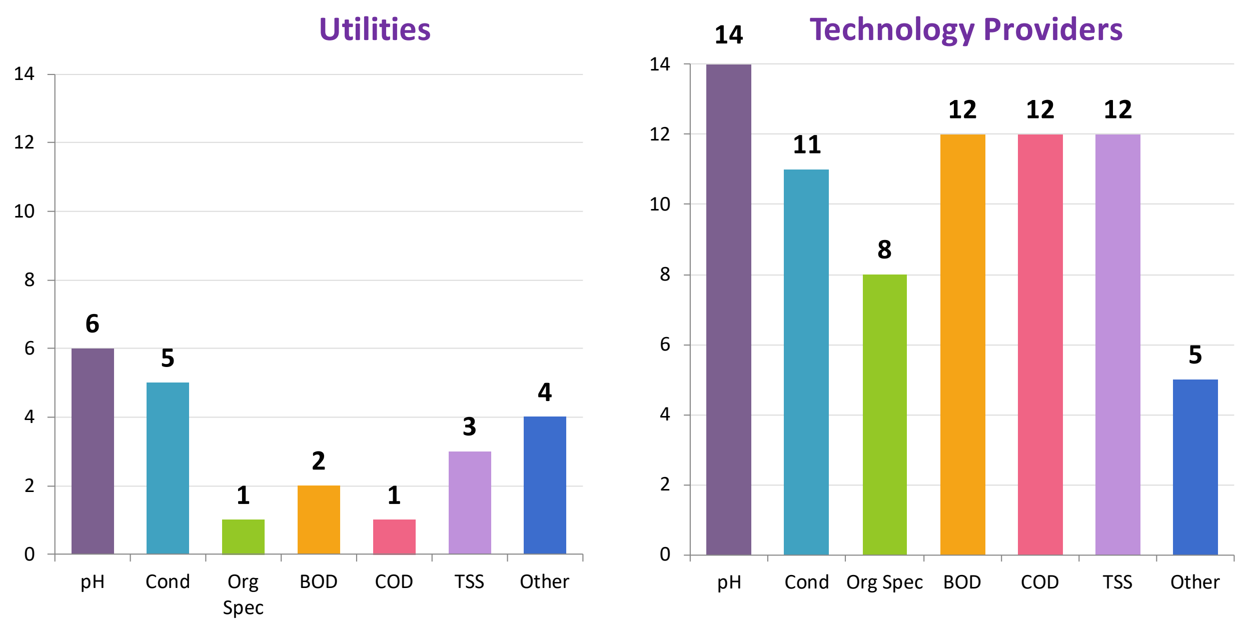


Figure 13. Online Parameters Measured in the Sewershed.

If your utility does use online sensors to measure water quality in the sewershed network, which parameters would you like to measure that you can't currently measure?

This question was directed only at utilities, and it links to the next question, which asks why they can't be measured. The survey results are shown in Figure 15.

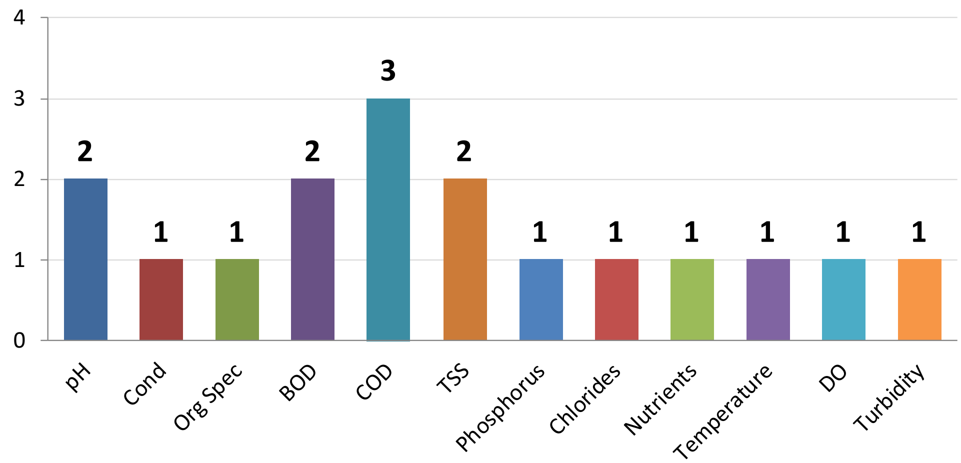


Figure 14. Parameters that Utilities Would Like to Measure.

For the parameters that you would like to measure, but currently can't, why can't you measure them?

Options provided to respondents were:

- No online sensors are available on the market for these parameters
- Online sensors for these parameters are too expensive to justify their use
- Current online sensors for these parameters are unreliable or require significant maintenance
- Other

Only utilities were posed this question, with 12 utilities responding. Figure 16 shows all the options were selected with the thought that sensors are unreliable in this environment or too expensive to justify being slightly more common than availability of sensors for the parameters of interest.

Other included "no need to monitor," "very new and not tested," and "lack of skilled personnel."

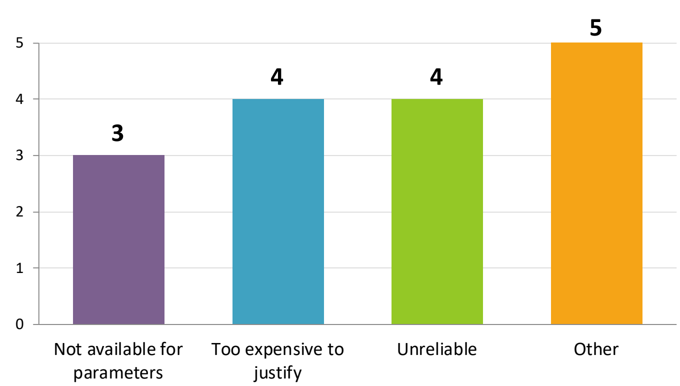


Figure 15. Reasons for not Measuring Certain Parameters.

If online sensors are not used, what are seen as the barriers for implementing them?

Respondents were asked to rate each of the items on a scale of 1 to 5 (1 as not a barrier; 5 as a significant barrier).

- Lack of suitable technology
- Too expensive (acquisition)
- Too expensive (operations and maintenance [O&M])
- Unreliable data (false alarms)
- Lack of skilled personnel
- Organizational barriers
- Lack of a business case
- Other

Results obtained using the 1-to-5 scale ratings did not provide any definitive results. The ratings were therefore adjusted to a Low/Neutral/High scale where 1 and 2 were combined to be “Low,” 3 was made “Neutral,” and 4 and 5 were combined to be “High.”

Results using the Low/Neutral/High rating scale are presented in Table 2. Thirteen utilities and 18 technology providers responded to this question. The cells highlighted in yellow are those representing greater than half of the survey respondents in each group. The results indicate the following:

- Utilities and technology providers see operation and maintenance costs as being a barrier to use.
- Technology providers also see that utilities believe the acquisition cost may be too high.
- Utilities don’t see a business case for using sensors.
- Utilities don’t believe that organizational barriers impede use of these technologies.
- Technology providers don’t believe that unreliable data is seen as an impediment to use of sensors.
- Technology providers don’t believe there is a lack of suitable technologies for measurement.

Table 2. Barriers to Use.

	Utilities			Technology Providers		
	Low	**Neutral**	**High**	**Low**	**Neutral**	**High**
Unreliable data (false alarms)	5	3	4	9	6	3
Too expensive (acquisition)	4	4	5	3	3	11
Too expensive (O&M)	2	4	7	3	4	11
Lack of skilled personnel	5	6	2	4	8	6
Organizational barriers	8	3	2	5	5	8
Lack of a business case	4	2	7	7	6	5
Lack of suitable technology	-	-	-	9	2	6

If any type of online sensors is used, what were the main driving forces (rationale) for adopting it?

Respondents were asked to rate each on a scale of 1 to 5 (1 as not important; 5 as a very important).

- Informative monitoring
- Real-time control
- Regulation/compliance monitoring
- Research
- Early warning system (sewershed or influent)
- Other

Results obtained using the 1-to-5 scale ratings did not provide any definitive results. The ratings were therefore adjusted to a Low/Neutral/High scale where 1 and 2 were combined to be "Low," 3 was made "Neutral," and 4 and 5 were combined to be "High."

Results using the Low/Neutral/High rating scale are presented in Table 3. Fourteen utilities and 18 technology providers responded to this question. The cells highlighted in yellow are those representing greater than half of the survey respondents in each group. The results indicate the following:

- Both utilities and technology providers believe the most important use for sensors is as part of an early warning system, followed by compliance monitoring, followed by real-time control.
- Research is not seen as an important reason to use sensors in a sewershed network.

Table 3. Rationale for Use of Sensors.

	Utilities			Technology Providers		
	Low	Neutral	High	Low	Neutral	High
Research	5	6	3	12	3	3
Real-time control	3	3	8	2	3	13
Regulation/compliance monitoring	2	2	9	1	3	14
Early warning system (sewershed or influent)	0	4	10	0	2	16
Informative monitoring	-	-	-	1	1	16

Where online sensors are used, what type of communications system is predominantly used?

This question asked respondents to select all that apply.

- Wired communication
- Local wireless, such as Bluetooth, wireless local area network (WLAN) (Institute of Electrical and Electronics Engineers [IEEE] 802.11)
- Wide area wireless, such as private radio networks
- Commercial wireless, such as cell phone providers or satellite data providers
- Other
- Not applicable

Fifteen utilities and 20 technology providers responded to this question. The dominant technology used is cell phone or satellite phone as shown in Figure 17. The responses included in "Other" were NarrowBand-Internet of Things (NB-IoT), Semtech LoRa, and Sigfox.

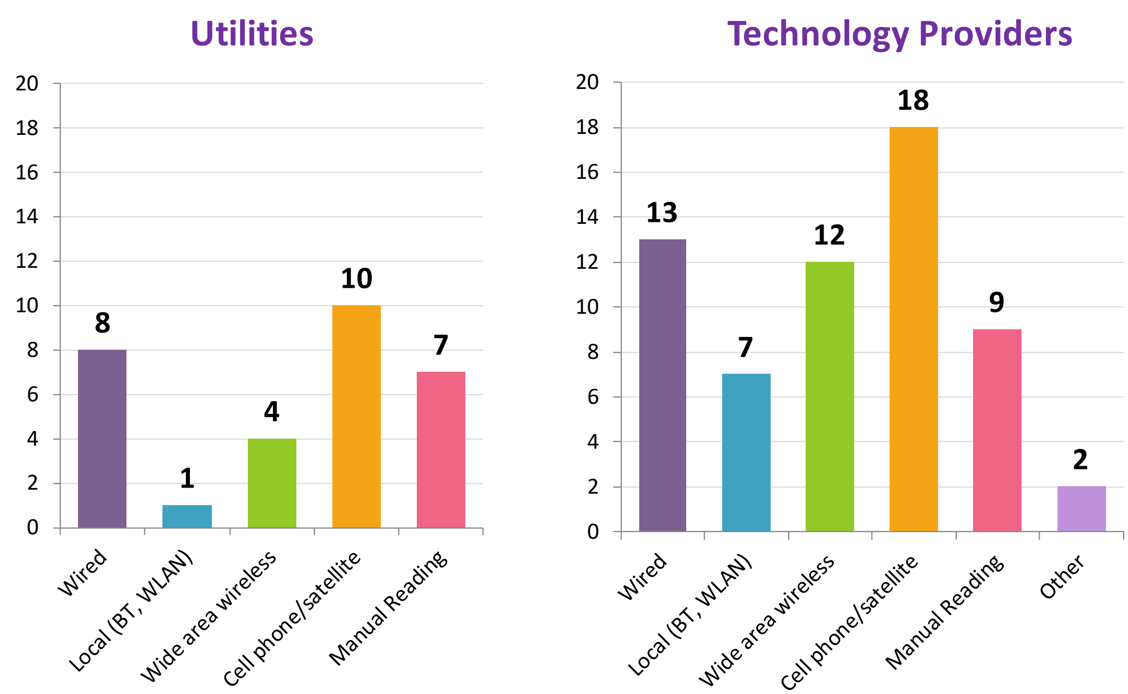


Figure 17. Communication Systems.

What is the average measurement frequency from online sensors in the sewershed network(s)?

- <1 minute
- 1 - 2 minutes
- 2 - 5 minutes
- 5 - 15 minutes
- 15 - 30 minutes
- 30 - 60 minutes
- 60 minutes
- Other

Results are provided in Figure 18. The 5-to-15 minute bracket is the most common.

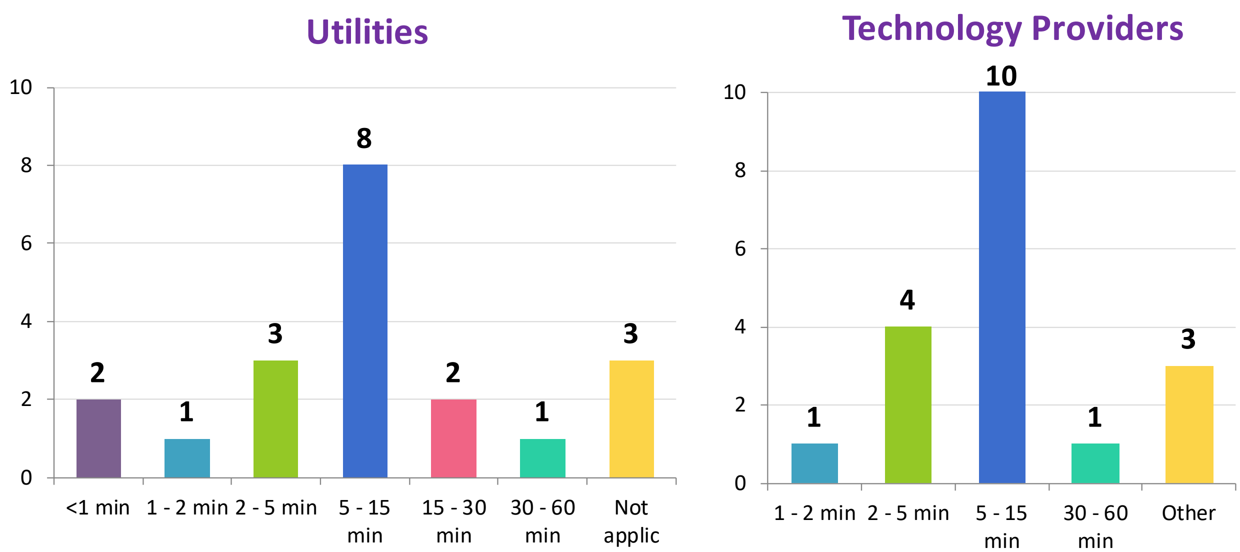


Figure 16. Average Measurement Frequency.

Is a supervisory control and data acquisition (SCADA) system installed and monitoring a sewershed network?

The results in Figure 19 indicate that SCADA systems are generally used in sewershed networks. Note that there was some inconsistency between responses to this question and “Does your utility use a pump control system. If so, what type?” in which 19 utilities responded with “connected to SCADA” while the response here indicates 16 utilities have SCADA. Likewise, the technology providers responded with 18 “connected to SCADA” and the response here indicates 19 have SCADA.

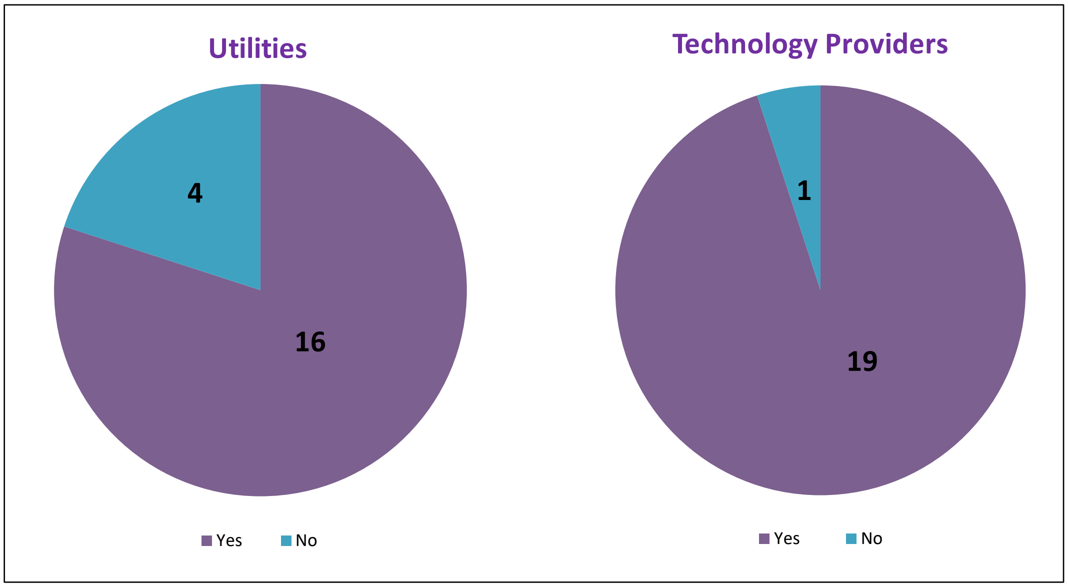


Figure 17. SCADA Use in Sewershed Networks.

Are sewer system assets typically mapped in a Geographic Information System (GIS)? If so, what type?

- Fully integrated GIS system
- Standalone GIS system (not integrated with other data systems)
- Computer-Aided Design (CAD) system
- Paper-based system
- Not applicable

The results in Figure 20 indicate that GIS is usually used for managing sewershed assets. There is an even split between the use of standalone GIS and fully integrated GIS.

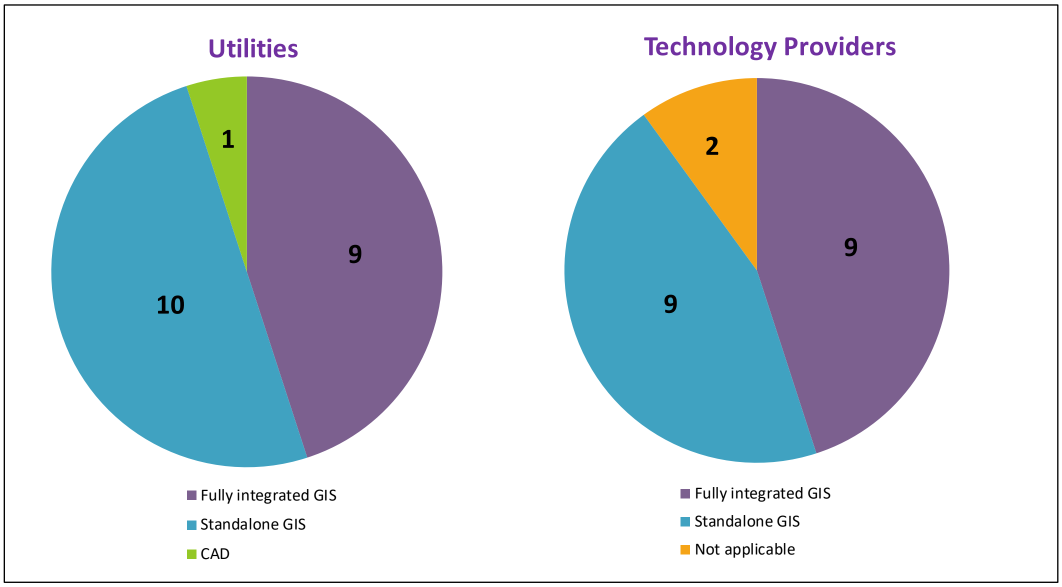


Figure 20. Use of GIS in Sewershed Networks.

What types of hydraulic modeling software are used?

This question asked respondents to select all that apply.

- None
- EPA SWMM
- InfoSWMM
- MIKE (DHI)
- HEC-RAS
- Other

The results presented in Figure 21 indicate that there is a variety of sewershed modelling software used by utilities with no dominant product. The results also indicated that most utilities used more than one software modelling application. “Other” includes InfoWorks ICM, CalSim, itwh KOSIM, SewerCAD, WaterCAD, XPSWMM, SWMMLIVE, and USGS HSPF.

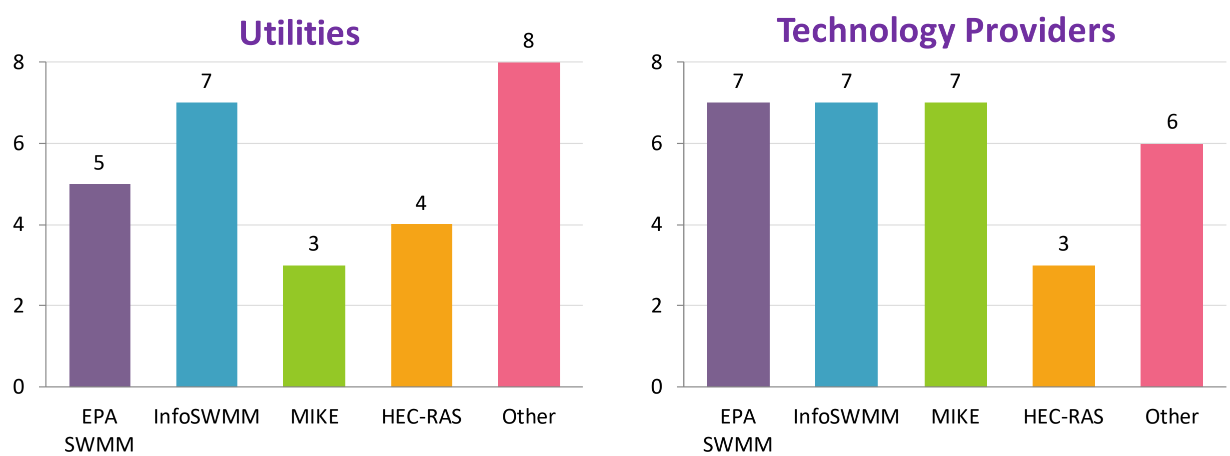


Figure 21. Modeling Software Used in Sewersheds.

What is typically used to analyze information from the different sewershed network data streams?

This question asked respondents to select all that apply.

- SCADA HMI
- Reports
- Analytics
- Predictive analytics
- Visualization (e.g., dashboards, plots)

Figure 22 presents the different systems used for analysis of the data produced for sewersheds. Visualization (as dashboards or plots) and reports are considered to be the most used methods for analysis. The “Other” category included consultants and “don't know”.

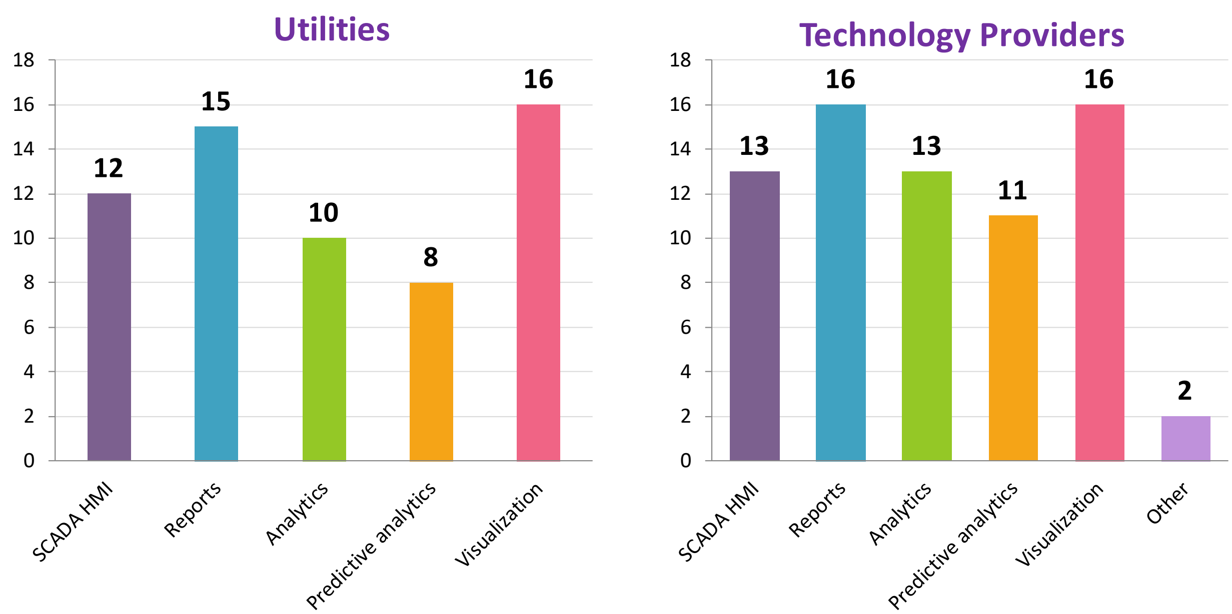


Figure 22. Analysis of Sewershed Data.

What does the information get used for?

This question asked respondents to select all that apply.

- Operational decision-making
- Short-term operations planning
- Short-term maintenance planning
- Long-term operations planning
- Long-term maintenance planning
- Capital expenditure planning
- Long-term asset management
- Other

Nineteen of the 20 utilities and 18 of the 20 technology providers responded to this question. The results presented in Figure 23 indicate that predominant use of information generated from the sewershed is to support operational decisions. The topics scoring the lowest were related to long term planning for both operations and maintenance. The category "other" includes I&I identification, regulatory reporting, plant performance evaluation, reports for authorities, and "better QA/QC data now used for longer term decisions."

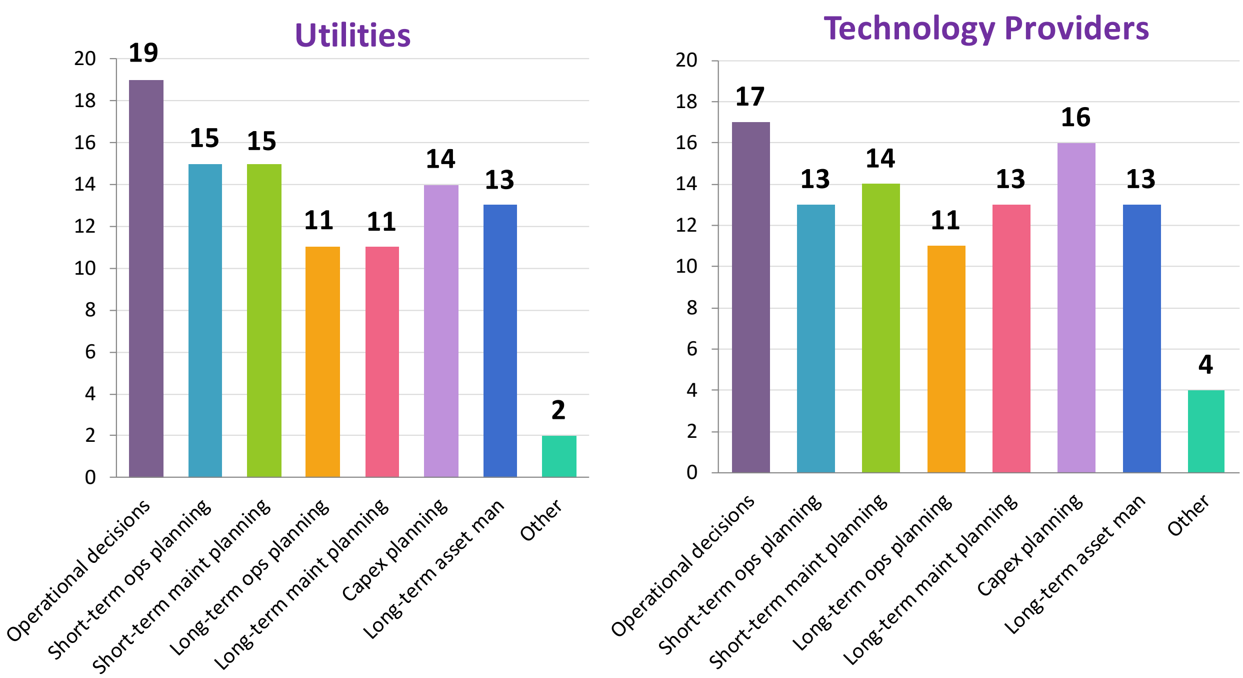


Figure 23. Use of Information.

Which of the following activities are part of your utility's Quality Assurance/Quality Control (QA/QC) program?

This question asked respondents to select all that apply.

- Commissioning of instruments (e.g., verification of proper equipment installation and operation)
- Routine instrument inspection, maintenance, and cleaning
- Comparison of online data with bench-top analysis
- Performance verification with performance standards/standard solutions
- Routine instrument calibration
- Other

Nineteen of the 20 utilities responded to this question. The results presented in Figure 24 indicate that the primary QA/QC activities undertaken by a utility relate to commissioning, routine maintenance, and routine calibration of instruments. One utility indicated its QC/QC program is contracted.

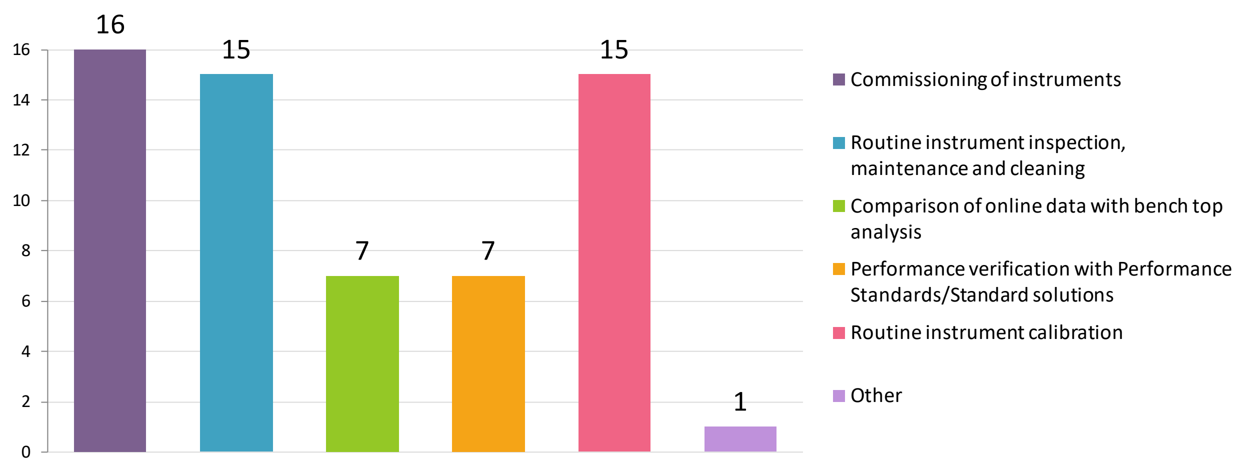


Figure 24. Utility QA/QC Activities.

Future Outlook

The survey results are presented and discussed using a general form of the survey questions.

Is there interest in using any of the following advanced, online sewershed network technologies or processes?

Respondents were asked to check all that apply.

- Real-time monitoring using sensors
- Predictive analytics
- Remote monitoring of collection systems
- Decision support systems (e.g., big data)
- Long-term asset management
- Automated control
- Other
- No interest

Sixteen of the 20 utilities responded to this question. The results in Figure 25 indicate that utilities are generally interested in learning more about available technologies to support their systems. Of particular interest to utilities is long-term asset management and remote monitoring.

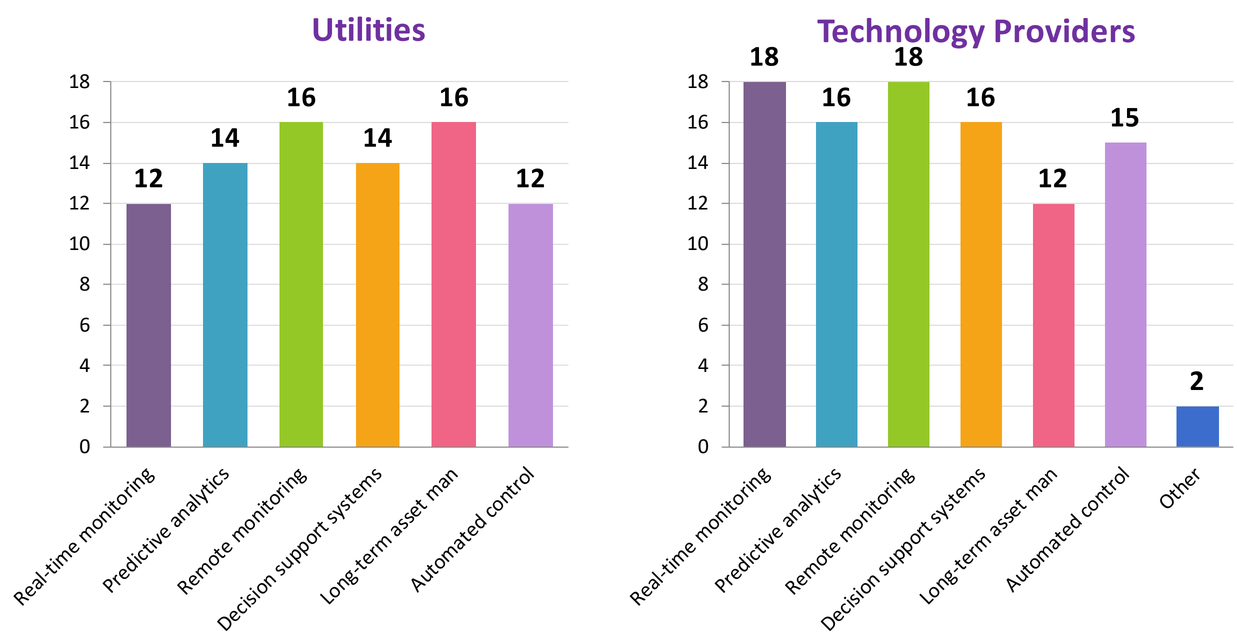


Figure 25. Potential Topics of Interest.

Is there an intent to significantly increase investments in advanced, online sewershed network management, as part of a long-term strategy?

- Yes, in the next five years
- Maybe, but not planned yet
- No

Responses from utilities shown in Figure 26 indicate that there is some commitment to increasing investment in advanced, online sewershed network management. Responses from technology providers are decidedly more optimistic.

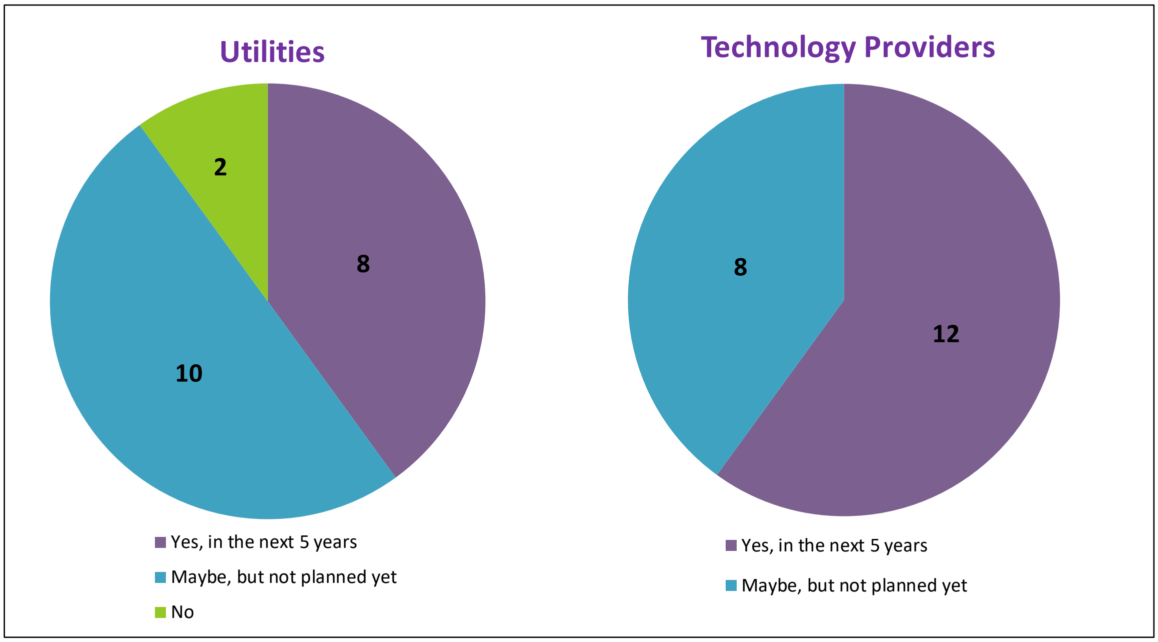


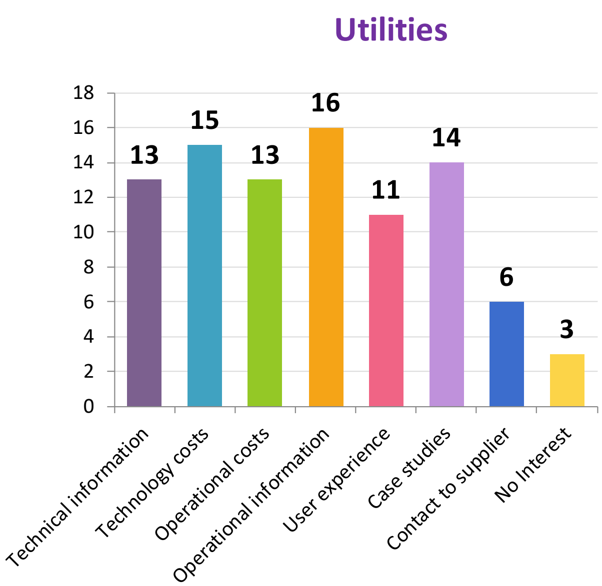
Figure 26. Intent for Long-Term Investment.

What type of information would be of interest regarding advanced, online sewershed network management?

This question asked respondents to select all that apply.

- Technical information/specifications
- Cost information (technology costs)
- Cost information (operational costs)
- Operational information (best practice, maintenance, calibration)
- User experience references/contact, details, advice on suitability for application
- Case studies
- Contact to supplier/manufacturer
- Other (please specify):
- No interest

The results from utilities shown in Figure 27 indicate that there is most interest in operational information and technology costs, whereas the technology providers expect that technology and operational costs are of most importance to a utility.



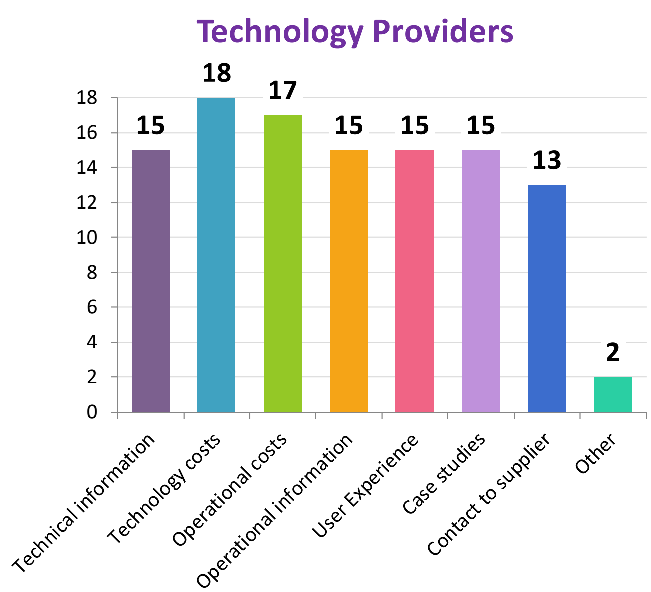


Figure 27. Information of Interest.

As a supplier of technologies to water and wastewater utilities, what new products and new capabilities do you expect will be available in the next five years?

Technology providers were surveyed about what they felt the future focus for the industry would be. This question asked respondents to select all that apply and provide details of expectations and expected value to the utility.

- Online sensor technologies
- New sensors for parameters that aren't currently measurable online
- Communications
- Predictive analytics
- Decision support systems (e.g., big data)
- Long-term asset management
- Automated control
- Other

Figure 28 presents a summary of the responses, with decision support systems and online sensor technologies being identified as where new capabilities will emerge in the next five years. The category "Other" included network modeling and real-time optimization, and more integration with currently isolated systems.

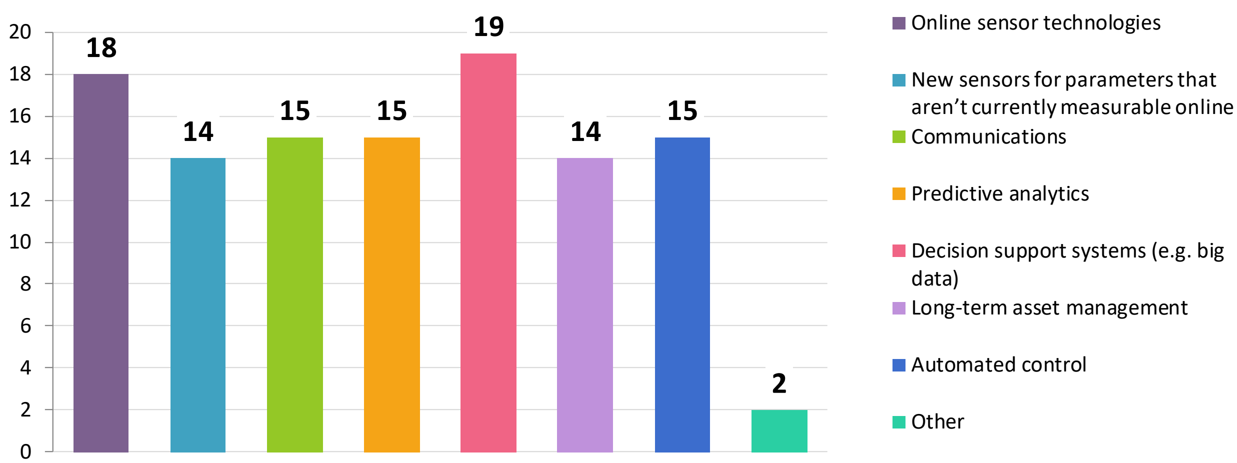


Figure 28. Future Capabilities Expected.

Additional comments or suggestions about what keeps you up at night.

Both utilities and technology providers were asked about what they saw as most important using the phrasing of this question. Only one response was received, which was "lack of risk management, lack of real-time information, lack of appropriate instrumentation and monitoring."

Summary/Conclusions

The surveys had responses from 20 utilities and 20 technology providers. Summary conclusions are:

- Challenges of greatest concern identified by utilities were capacity issues and I&I.
- Challenges of greatest concern to utilities, as observed by technology providers, were capacity issues and CSOs.
- Wastewater utilities typically only measure water quality at the treatment plant, with some measuring water quality in the collection system, and fewer measuring water quality in the receiving streams.
- The main reasons utilities provided for not measuring parameters of interest were that they are considered too expensive to justify and are unreliable in the wastewater environment.
- Utilities often use more than one hydraulic model.
- The majority of utilities surveyed expressed interest in learning more about the application of advanced technologies for use in the sewershed, such as real-time monitoring using sensors, predictive analytics, decision support systems, and automated control.
- Both utilities and technology providers indicated technology costs as the type of information that would be of interest regarding advanced, online sewershed network management.
    - Utilities indicated operational information as the second highest.
    - Technology providers indicated operational costs as the second highest.

Attachment A –
Survey Questions for Wastewater Utilities

Advanced Sewershed Monitoring Survey - Utilities

Water Environment and Reuse Foundation (WE&RF)/CH2M Study

The Internet of Things (IoT) is driving a revolution of sensing technologies and communication platforms, spurring the development of advanced sensors that provide access to new data streams for the wastewater industry. The goal of this research study is to provide a basic roadmap for the application of remote sensor technology to address the challenges facing wastewater utilities. By participating in this survey, you will help determine the current challenges, capabilities, and state of designing and implementing sensor networks in urban sewersheds.

Utility Information

All responses will be kept confidential and presented only on an aggregated basis. * Denotes a mandatory field.

Your Name

Your Title

Utility Name *

Utility City, State (if applicable) *

Utility Country *

1. **Is your utility a public or private entity?** *

- ○ Public
- ○ Private

2. **What types of facilities does your utility currently manage? Please select all that apply.** *

- ☐ Drinking Water
- ☐ Wastewater
- ☐ Stormwater
- ☐ Water Reuse

3. **What population does your utility serve?** *

- Less than 100,000
- 100,000 – 299,999
- 300,000 – 599,999
- 600,000 – 999,999
- 1,000,000 or more

4. **What types of sewer collection systems (sewershed network) does your utility manage? Please select all that apply.** *

- Combined sewer system
- Separate sewer system
- Separate stormwater system
- Other - Write In (Required)

*

5. **What is the estimated total length of each type of pipeline in your sewershed network? (Please specify if miles or km).** *

Gravity

Force main/pressurized

Regulatory Environment

6. **Is your utility required to report to a regulatory authority? Please select all that apply.**

- ☐ Periodic operational reports
- ☐ Reporting of overflows/spills
- ☐ Periodic inspections
- ☐ Other - Write In (Required)

*

What is the frequency of your reporting? (hours)

7. **FOR U.S. UTILITIES: Are you currently under a regulatory agreement such as a Consent Decree or Stipulated Order?**

- ○ Yes
- ○ No

Challenges

8. **What are your utility's main sewershed network challenges/services? Please rate the current situation of each of the following challenges to your utility (1-5, 1 = not a challenge to our utility; 5 = challenge that requires immediate attention/solution):** *

	1	2	3	4	5
Pump (lift) station upgrades/improvements	○	○	○	○	○
Compliance monitoring (regulation)	○	○	○	○	○
Capacity issues (inflow and infiltration)	○	○	○	○	○
Inter-agency conflict/communication	○	○	○	○	○
Combined Sewage Overflows (CSO's)	○	○	○	○	○
Sanitary Sewage Overflows (SSO's)	○	○	○	○	○
External flooding and pollution	○	○	○	○	○
Customer flooding	○	○	○	○	○
Asset management	○	○	○	○	○

Technology Utilization

9. **How many pump (lift) stations are located throughout your sewershed network? [Approximate #]** *

10. **Does your utility use a pump station control system, if so, to what type? Please select all that apply.**

- [ ] Standalone
- [ ] Auto Dialer Alarm System (detects pump failure and/or high wet well levels)
- [ ] Annunciator system (GSM/GPRS/3G based)
- [ ] Connected to SCADA system
- [ ] Relay Logic System (tied to float switches)
- [ ] Programmable Logic Controller (PLC) or micro-processor-based
- [ ] Intelligent Pump Station Management (provides integrated real-time control of stations)
- [ ] Other - Write In (Required)

*

11. **Which online sensors does your utility use to measure water levels or flow in the sewershed network(s)? Please select all that apply.**

- [ ] Level sensors
- [ ] Flow meters
- [ ] Other - Write In (Required)

*

12. **Which rain gauge sensors does your utility use to measure and transmit data about current sewershed weather conditions? Please select all that apply.**

- ☐ Physical gauges (e.g., tipping bucket)
- ☐ Virtual gauges (e.g., radar)
- ☐ Other - Write In (Required)

*

13. **Do these gauges provide historical or real-time weather data? Please select all that apply.**

- ☐ Historical
- ☐ Real-time
- ☐ Batch readings

14. **Does your utility use online sensors to measure water quality in the sewershed network(s)? Please select all that apply.**

- ☐ At the treatment plant
- ☐ In the sewershed network
- ☐ Receiving streams

15. **If your utility <u>does use</u> online sensors to measure water quality in the sewershed network, which parameters do you measure? Please select all that apply.**

- ☐ pH
- ☐ Conductivity (EC)
- ☐ Organic Spectrum
- ☐ Biological Oxygen Demand
- ☐ Chemical Oxidation Demand
- ☐ Total Suspended Solids
- ☐ Other - Write In (Required)

*

16. **If your utility <u>does use</u> online sensors to measure water quality in the sewershed network, which parameters would you like to measure that you can't currently measure?**

17. **For the parameters that you would like to measure, but currently can't, why can't you measure them? Please select all that apply.**

- ☐ There are no online sensors available on the market for these parameters
- ☐ Online sensors for these parameters are too expensive to justify their use
- ☐ Current online sensors for these parameters are unreliable or require significant maintenance
- ☐ Other - Write In (Required)

*

18. **If your utility <u>does not use</u> any type of online sensors, what barriers do you see for implementing them? Please rate each on a scale of 1-5 (1 as not a barrier; 5 as a significant barrier).**

	1	2	3	4	5
Unreliable data (False alarms)	○	○	○	○	○
Too expensive (acquisition)	○	○	○	○	○
Too expensive (O&M)	○	○	○	○	○
Lack of skilled personnel	○	○	○	○	○
Organizational barriers	○	○	○	○	○
Lack of a business case	○	○	○	○	○

19. **If your utility <u>does use</u> any type of online sensors, what were the main driving forces (rationale) for adopting them? Please rate each on a scale of 1-5 (1 as not important; 5 as a very important).**

	1	2	3	4	5
Research	○	○	○	○	○
Real-time Control	○	○	○	○	○
Regulation/Compliance Monitoring	○	○	○	○	○
Early Warning System (sewershed or influent)	○	○	○	○	○

20. **If your utility <u>does use</u> online sensors, what type of communications system do you use predominantly? Please select all that apply.**

- [ ] Wired communication
- [ ] Local wireless, such as Bluetooth, WLAN (IEEE 802.11)
- [ ] Wide area wireless, such as private radio networks
- [ ] Commercial wireless, such as cell phone providers or satellite data providers
- [ ] Manual Reading
- [ ] Other - Write In (Required)

*

21. **What is your utility's <u>average</u> measurement frequency from online sensors in the sewershed network(s)?** *

- ( ) <1 min
- ( ) 1 - 2 min
- ( ) 2 - 5 min
- ( ) 5 - 15 min
- ( ) 15 - 30 min
- ( ) 30 - 60 min
- ( ) 60 min
- ( ) Other - Write In (Required)

*

- ( ) Not applicable

22. **Does your utility have a supervisory, control and data acquisition system (SCADA) installed and monitoring a sewershed network?** *

- ○ Yes
- ○ No

23. **Does your utility currently have sewer system assets mapped in a Geographic Information System (GIS)? If so, what type?** *

- ○ Fully integrated GIS system
- ○ Standalone GIS system (not integrated with other data systems)
- ○ Computer Aided Design (CAD) system
- ○ Paper-based system
- ○ Not applicable

24. **What types of hydraulic modeling software does your utility use? Please select all that apply.**

- ☐ EPA SWMM
- ☐ InfoSWMM
- ☐ MIKE
- ☐ HEC-RAS
- ☐ Other - Write In (Required)

*

25. **Does your utility use any of the following to analyze information from the different sewershed network data streams? Please select all that apply.**

- ☐ SCADA HMI
- ☐ Reports
- ☐ Analytics
- ☐ Predictive analytics
- ☐ Visualization (e.g., dashboards, plots)
- ☐ Other - Write In (Required)

*

26. **What does the information get used for? Please select all that apply.**

- ☐ Operational decision making
- ☐ Short-term operations planning
- ☐ Short-term maintenance planning
- ☐ Long-term operations planning
- ☐ Long-term maintenance planning
- ☐ Capital expenditure planning
- ☐ Long-term asset management
- ☐ Other - Write In (Required)

*

27. **Which of the following activities are part of your utility's QA/QC program? Please select all that apply.**

- [ ] Commissioning of instruments (e.g. verification of proper equipment installation and operation)
- [ ] Routine instrument inspection, maintenance and cleaning
- [ ] Comparison of online data with bench top analysis
- [ ] Performance verification with Performance Standards/Standard solutions
- [ ] Routine instrument calibration
- [ ] Other - Write In (Required)

*

Future Outlook

28. **Does your utility have interest in using any of the following advanced, online sewershed network technologies or processes? Please select all that apply.**

- [ ] Real-time monitoring using sensors
- [ ] Predictive analytics
- [ ] Remote monitoring of collection systems
- [ ] Decision support systems (e.g. big data)
- [ ] Long-term asset management
- [ ] Automated control
- [ ] Other - Write In (Required)

*

29. **Does your utility intend to significantly increase your investments in advanced, online sewershed network management, as part of your long-term strategy?** *

- Yes, in the next 5 years
- Maybe, but not planned yet
- No

30. **What type of information would your utility be looking for regarding advanced, online sewershed network management? Please select all that apply.** *

- Technical information/specifications
- Cost information (technology costs)
- Cost information (operational costs)
- Operational information (best practice, maintenance, calibration)
- User experience references/contact details/advice on suitability
- Case studies
- Contact to supplier/manufacturer
- Other - Write In (Required) *
- No Interest

31. **Additional comments about what keeps you up at night:**

Thank You!

Thank you for taking our survey. Your response is very important to us.

Attachment B –
Survey Questions for Technology Providers

Advanced Sewershed Monitoring Survey - Solution Providers

Water Environment and Reuse Foundation (WE&RF)/CH2M Study

The Internet of Things (IoT) is driving a revolution of sensing technologies and communication platforms, spurring the development of advanced sensors that provide access to new data streams for the wastewater industry. The goal of this research study is to provide a basic roadmap for the application of remote sensor technology to address the challenges facing wastewater utilities. By participating in this survey, you will help determine the current challenges, capabilities, and state of designing and implementing sensor networks in urban sewersheds.

Each survey participant will receive a **free copy** of the aggregated survey results and we will raffle a **$50 Amazon Gift Card** for one lucky survey participant.

Introductory Information

All responses will be kept confidential and presented only on an aggregated basis. * Denotes a mandatory field.

Your Name

Your Title

Your Company

1. **What technologies does your organization supply to water and wastewater utilities? Please select all that apply.** *

- ☐ Sensors
- ☐ SCADA
- ☐ Analytics and visualization software
- ☐ Other - Write In (Required)

*

2. **What types of facilities do your customers currently manage? Please select all that apply.** *

- ☐ Drinking Water
- ☐ Wastewater
- ☐ Stormwater
- ☐ Water Reuse

3. **What types of sewer collection systems (sewershed network) do your customers manage? Please select all that apply.** *

- ☐ Combined sewer system

- [ ] Separate sewer system
- [ ] Separate stormwater system
- [ ] Other - Write In (Required)

*

4. **What would be the estimated total length of each type of pipeline in your typical customers' sewershed network? (Please specify if miles or km).** *

Gravity

Force main/pressurized

Regulatory Environment

5. **Are any of your customers required to report to a regulatory authority? Please select all that apply, and indicate how many customers for each. Please select all that apply.**

- [ ] Periodic operational reports
- [ ] Reporting of overflows/spills
- [ ] Periodic inspections
- [ ] Other - Write In (Required)

*

6. **FOR U.S. PROVIDERS: Are any of your U.S. customers currently under a regulatory agreement such as a Consent Decree or Stipulated Order? If so, how many customers?**

Yes

No No

Challenges

7. **What are your customers' main sewershed network challenges/services? Please rate the current situation of each of the following challenges to your customers (1-5, 1 = not a challenge to our utility; 5 = challenge that requires immediate attention/solution)** *

	1	2	3	4	5
Aging infrastructure	○	○	○	○	○
Compliance monitoring (regulation)	○	○	○	○	○
Capacity issues (inflow and infiltration)	○	○	○	○	○
Pump (lift) station upgrades/improvements	○	○	○	○	○
Inter-agency conflict/communication	○	○	○	○	○
Combined Sewage Overflows (CSO's)	○	○	○	○	○
Sanitary Sewage Overflows (SSO's)	○	○	○	○	○
External flooding and pollution	○	○	○	○	○
Customer flooding	○	○	○	○	○
Asset management	○	○	○	○	○

Technology Utilization

8. **How many pump (lift) stations would be located in your typical customers' sewershed network? [Approximate #]** *

9. **Do your customers typically use a pump station control system, if so, what type, and did your company supply it? Please select all that apply.**

- ☐ Standalone
- ☐ Auto Dialer Alarm System (detects pump failure and/or high wet well levels)
- ☐ Annunciator system (GSM/GPRS/3G based)
- ☐ Connected to SCADA system
- ☐ Relay Logic System (tied to float switches)
- ☐ Programmable Logic Controller (PLC) or micro-processor-based
- ☐ Intelligent Pump Station Management (provides integrated real-time control of stations)
- ☐ Other - Write In (Required)

*

---

10. **Which online sensors do your customers use to measure water levels or flow in the sewershed network(s)? Please select all that apply.**

- ☐ Level sensors
- ☐ Flow meters

Please specify if your company supplies such sensors:

- ☐ Level Sensors
- ☐ Flow Meters

---

11. **Which rain gauge sensors do your customers use to measure and transmit data about current sewershed weather conditions? Please select all that apply.**

- ☐ Physical gauges (e.g., tipping bucket)

- ☐ Virtual gauges (e.g., radar)
- ☐ Other - Write In (Required)

  ____________ *

Please specify if your company supplies such sensors:

- ☐ Physical gauges
- ☐ Virtual gauges

12. **Do these gauges provide historical or real-time weather data? Please select all that apply.**

- ☐ Historical
- ☐ Real-time
- ☐ Batch readings

13. **Do any of your customers use online sensors to measure water quality in the sewershed network(s)? Please select all that apply.**

- ☐ At the treatment plant
- ☐ In the sewershed network
- ☐ Receiving streams

14. Please specify if your company supplies online water quality sensors:

- ☐ At the treatment plant
- ☐ In the sewershed network
- ☐ Receiving streams

15. **If any of your customers do use online sensors to measure water quality in the sewershed network, which parameters do they measure? Please select all that apply.**

- ☐ pH
- ☐ Conductivity (EC)
- ☐ Organic Spectrum
- ☐ Biological Oxygen Demand
- ☐ Chemical Oxidation Demand
- ☐ Total Suspended Solids
- ☐ Other - Write In (Required)

*

Please specify which parameters your company measures through online water quality sensors:

- ☐ pH
- ☐ Conductivity (EC)
- ☐ Organic Spectrum
- ☐ Biological Oxygen Demand
- ☐ Chemical Oxidation Demand
- ☐ Total Suspended Solids
- ☐ Other - Write In (Required)

*

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16. **For your customers that <u>do not use</u> any type of online sensors, what barriers do they see for implementing them? Please rate each on a scale of 1-5 (1 as not a barrier; 5 as a significant barrier).**

	1	2	3	4	5

	1	2	3	4	5
Lack of suitable technology	○	○	○	○	○
Too expensive (acquisition)	○	○	○	○	○
Too expensive (O&M)	○	○	○	○	○
Unreliable data (False alarms)	○	○	○	○	○
Lack of skilled personnel	○	○	○	○	○
Organizational barriers	○	○	○	○	○
Lack of a business case	○	○	○	○	○

17. **For your customers that <u>do use</u> any type of online sensors, what were the main driving forces (rationale) for adopting them? Please rate each on a scale of 1-5 (1 as not important; 5 as a very important).**

	1	2	3	4	5
Informative Monitoring	○	○	○	○	○
Real-time Control	○	○	○	○	○
Regulation/Compliance Monitoring	○	○	○	○	○
Research	○	○	○	○	○
Early Warning System (sewershed or influent)	○	○	○	○	○

18. **Where your customers <u>do use</u> online sensors, what type of communications system do they use predominantly? Please select all that apply.**

- ☐ Wired communication
- ☐ Local wireless, such as Bluetooth, WLAN (IEEE 802.11)
- ☐ Wide area wireless, such as private radio networks
- ☐ Commercial wireless, such as cell phone providers or satellite data providers
- ☐ Manual Reading
- ☐ Other - Write In (Required)

  ________ *

---

19. **What are your customers' <u>average</u> measurement frequency from online sensors in the sewershed network(s)?** *

- ○ <1 min
- ○ 1 - 2 min
- ○ 2 - 5 min
- ○ 5 - 15 min
- ○ 15 - 30 min
- ○ 30 - 60 min
- ○ 60 min
- ○ Other - Write In (Required)

  ________ *

- ○ Not applicable

---

20. **Do your customers typically have a supervisory, control and data acquisition system (SCADA) installed and monitoring a sewershed network?** *

- ○ Yes

◯ No

21. **Do your customers typically have sewer system assets mapped in a Geographic Information System (GIS)? If so, what type?** *

◯ Fully integrated GIS system

◯ Standalone GIS system (not integrated with other data systems)

◯ Computer Aided Design (CAD) system

◯ Paper-based system

◯ Not applicable

22. **What types of hydraulic modeling software are your customers using? Please select all that apply.**

☐ EPA SWMM

☐ InfoSWMM

☐ MIKE

☐ HEC-RAS

☐ Other - Write In (Required)

*

23. **Do your customers typically use any of the following to analyze information from the different sewershed network data streams? Please select all that apply.**

☐ SCADA HMI

☐ Reports

☐ Analytics

☐ Predictive analytics

- ☐ Visualization (e.g., dashboards, plots)
- ☐ Other - Write In (Required)

  *

---

24. **What does the information get used for? Please select all that apply.**

- ☐ Operational decision making
- ☐ Short-term operations planning
- ☐ Short-term maintenance planning
- ☐ Long-term operations planning
- ☐ Long-term maintenance planning
- ☐ Capital expenditure planning
- ☐ Long-term asset management
- ☐ Other - Write In (Required)

  *

Future Outlook

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25. **Do your customers have interest in using any of the following advanced, online sewershed network technologies or processes? Please check all that apply.**

- ☐ Real-time monitoring using sensors
- ☐ Predictive analytics
- ☐ Remote monitoring of collection systems
- ☐ Decision support systems (e.g. big data)
- ☐ Long-term asset management
- ☐ Automated control

- [ ] Other - Write In (Required)

  ______ *

26. **Do your customers typically intend to significantly increase their investments in advanced, online sewershed network management, as part of their long-term strategy?** *

- ◯ Yes, in the next 5 years
- ◯ Maybe, but not planned yet
- ◯ No

27. **What type of information would your customers be looking for regarding advanced, online sewershed network management? Please select all that apply.** *

- [ ] Technical information/specifications
- [ ] Cost information (technology costs)
- [ ] Cost information (operational costs)
- [ ] Operational information (best practice, maintenance, calibration)
- [ ] User Experience References/contact details Advice on suitability for application
- [ ] Case studies
- [ ] Contact to supplier/manufacturer
- [ ] Other - Write In (Required)

  ______ *

- [ ] No Interest

28. **As a supplier of technologies to water and wastewater utilities, where do you expect new products will new**

capabilities will be available in the next 5 years? Please select all that apply and provide details of expectations and expected value to the utility. *

- ☐ Online sensor technologies
- ☐ New sensors for parameters that aren't currently measurable online
- ☐ Communications
- ☐ Predictive analytics
- ☐ Decision support systems (e.g. big data)
- ☐ Long-term asset management
- ☐ Automated control
- ☐ Other - Write In (Required)

*

29. **Additional comments or suggestions about what keeps your customers up at night:**

Submit

0%

APPENDIX B

Task 1 – Survey Wastewater Utilities and Technology Companies – Summary of Case Studies

Designing Sensor Networks and Locations on an Urban Sewershed Scale

Task 1 – Survey Wastewater Utilities and Technology Companies – Summary of Case Studies

PREPARED FOR:	Water Environment & Research Foundation
PREPARED BY:	CH2M
DATE:	January 29, 2018
PROJECT NUMBER:	SENG6R16

The plan for *Task 1 – Survey Wastewater Utilities and Technology Companies* of project SENG6R16 included a survey and request for case studies. To support this approach, those utilities and technology providers that responded to the industry survey distributed in Task 1 were separately requested to provide a documented case study that they felt could be educational for other utilities. This Technical Memorandum provides a summary of the case studies received.

Approach

To assist with the comparison and analysis of the case study details, a template (Attachment A) was provided to organizations that indicated an interest in providing a case study. Case studies were received from six wastewater utilities and four technology providers (Attachment B). Considering the infancy of implementing sewershed advanced monitoring programs in the industry, the small number of case studies received was not surprising.

Monitoring Goals

The case studies provided insight into the main goals that utilities had when considering monitoring. These goals were sometimes related to imposed penalties, such as a consent decree, but often were internally focused with a target of improving operations generally. The monitoring goals from all received case studies can be summarized as follows:

- Managing the system as efficiently as possible
- Providing accurate and timely reporting to meet combined sewer overflow (CSO) National Pollutant Discharge Elimination System (NPDES) Permit requirements
- Provide timely response to system problems and inform maintenance activities
- Meet requirements of consent decrees
- Allow hydraulic model calibration

- Prevent, report, and respond to overflows
- Identify and prioritize capital improvement projects
- Bill neighboring municipalities that send their wastewater through the water resource recovery facility (WRRF)
- Provide support during wet weather operations by providing near-time data and visual aids
- Provide backup monitoring in critical locations adjacent to waterways and commercial areas

Parameters Monitored

The only parameter monitored by all utilities represented in the case studies was level. In order of frequency represented, the parameters mentioned in the case studies that are currently being measured include these:

1. Level
2. Flow
3. Velocity
4. Pressure
5. Temperature
6. Conductivity
7. pH
8. Oxygen reduction potential (ORP)
9. Rainfall

Communications

The discussion of communications in the case studies indicated that the selection of the communications medium is a function of location (such as inside existing facilities) and when the instrumentation was installed. Generally, instrumentation inside existing facilities is connected using 4-20 mA cable, Ethernet cable, or fiber as this is readily available. Where instrumentation is at a remote location, the options for communications used are these:

- Unlicensed spread spectrum radio
- Cellular (2G/3G)
- Satellite (Iridium)

Analytics and Visualization

Typically, analytics and visualization was performed using the existing supervisory control and data acquisition (SCADA) system to provide trending and alarms. Some sensors, such as SmartCover, ADS, and Hach instrumentation, transmitted the data collected to the sensor provider's cloud, which also included analytics and visualization capabilities. Specialized, dedicated analytics and visualization was performed in only two of the case studies.

Examples of Use

Examples of the use of the instrumentation installed included the following:

- Support routine maintenance by monitoring flow and buildup in pipes, pump stations, and CSOs.
- Assess the performance of the system, looking to optimize the operation of existing facilities.
- Support hydraulic modeling and to build historical profiles of sites.

- Support wet weather system management by monitoring the collection system during wet weather events.
- Provide a means of accurately billing for wastewater treatment.
- Support identifying wastewater sources that may impact the wastewater treatment plant (WWTP).

Summary/Conclusions

The case studies involved sewersheds of various sizes and complexities representing a good cross-section of the industry.

Monitoring the sewershed was generally seen as useful to support other utility goals such as optimization of the system or reduction in capital expenditure. Monitoring was also used to support the resolution of imposed actions such as consent decrees.

Currently, very few parameters are typically monitored, with level and flow being the predominant parameters. Monitoring water quality and other similar parameters is rarely used in the sewershed.

The majority of case studies involved the use of a small number of sensors, located in specific areas of interest, such as a part of the system with previous problems that required minimal analytics and visualization. Case studies that aimed at managing the entire system involved complex analytics and visualization of the entire sewershed.

Attachment A – Template for Case Studies

WE&RF Project SENG6R16 *Designing Sensor Networks and Locations on an Urban Sewershed Scale* – Case Study Template

The purpose of this template is to elicit information about various case studies for collation, comparison, and analysis. The topics listed are therefore seen as useful for stimulating the thought process about the case study and identifying topics that we wish to explore further. Under each heading we have tried to include examples of the type of information that we are interested in seeing. These examples are by no means exhaustive, so feel free to include as much information as you wish.

Case Study Introduction (Include a photo)

Provide contact and utility information. Indicate if this information can be included in the final published case study results.

Contact Information (Name, Email, Phone):

Utility Name:

Utility Location:

Utility Address:

Size:

- Number of customers:
- Number of connections:
- Area covered:
- Miles of sewer lines:
    - Gravity
    - Pressurized
- Sewer type (e.g., combined, sanitary):

Other information:

Challenges

Describe existing and future challenges.

Monitoring Goals

Describe the goals of the monitoring system being used (e.g., saving money, reacting to a consent decree, optimizing system).

Sensors and Parameters

List the parameters being measured in the sewershed:

- Physical (e.g., level, flow
- Water quality (e.g., BOD)
- Others (e.g., rainfall, air quality)

Please include:

- Selected sensor manufacturers
- Decision making criteria for parameter and sensor selection.

Sensor locations

Provide details on where measurements are taken and why these locations were selected.

Communications

Provide details on the type(s) of communications used for transferring data from each location including:

- Locations inside utility facilities
- Locations that are remote from facilities

Communication types might include wired, licensed radio, cellular, LoRa, etc.

Analytics, User Interface, Visualization

Provide information about data analytics, the user interface, and visualization.

- Are these provided by existing systems such as SCADA, or dedicated systems?
- Do they use complex mathematical algorithms?
- What is provided for visualization and understanding of the data?
- How is it used in day-to-day operations?
- Is the system stand-alone or does it link to other systems for input (e.g., weather forecasting sites) or output (e.g., management dashboards, maintenance planning systems)?

Examples of Use

Provide any examples where the system:

- Saved money in a critical situation
- Saved money in routine operations
- Prevented or mitigated a non-compliance situation (e.g., CSO)

Lessons Learned

Detail the lessons learned when developing, implementing, and maintaining the sewershed monitoring program.

Additional Information

Provide any additional information about your utility that you would like to have represented.

Attachment B – Case Studies

Bellevue Utilities (Bellevue, Washington)

Image: https://upload.wikimedia.org/wikipedia/commons/2/21/Aerial_Bellevue_Washington_November_2011.jpg

SEWERSHED INFORMATION

CUSTOMERS:	~140,000
CONNECTIONS:	~40,000
AREA:	37 sq. miles
GRAVITY:	~500 miles

CHALLENGES	Bellevue has a relatively low rate of SSOs, averaging just under four overflows per 100 miles per year. The majority of those overflows are caused by a combination of roots, debris, and fats/oils/grease (FOG). Only a few are caused by structural issues. Bellevue has some capacity-related SSOs, but those are relatively infrequent (once every 5+ years). Similar to other agencies, Bellevue's system is aging and requires replacement. More than two-thirds of the system is greater than 60 years old. Bellevue's most costly asset replacement will be its lake lines. Bellevue has 19 miles of lake lines, which will require replacement over the next five to 25 years.
MONITORING GOALS	Monitoring is done primarily to report and respond to overflows. Bellevue does not have a consent decree. Bellevue does not actively use monitoring data to optimize its system.
SENSORS AND PARAMETERS	• Physical (e.g., level, flow): Bellevue monitors level and uses an algorithm to calculate flow at its 46 pump and flush stations. • Water quality (e.g., BOD): Bellevue does not monitor for water quality in its wastewater system. • Others (e.g., rainfall, air quality): Bellevue monitors for rainfall using a system of 10+ rain gauges. Bellevue has a few portable level sensors that are used for monitoring "high level" at a select number of manholes near Lake Washington. These are primarily used in areas where there has been repeat SSO problems, usually as a result of debris or FOG from an upstream customer.

SENSOR MANUFACTURERS	Varies
SENSOR LOCATIONS	• All sensors are located at operable facilities, which is primarily pump and flush stations. Bellevue has 46 pump and flush stations. • A few portable level sensors are reserved for areas where there have been repeat SSO problems. Those are generally located near the waterfront.
COMMUNICATIONS	• Locations inside utility facilities: All communications from utility facilities (i.e., pump or flush stations) are accomplished via lease lines. • Locations that are remote from facilities: Bellevue has a few portable sensors that use wireless cellular communications. These are for reporting high levels in manholes.
ANALYTICS/USER INTERFACE/ VISUALIZATION	• The analytics, user interface, and visualization are provided by the Utilities' Wonderware SCADA system. This system is also integrated with the drinking water and stormwater SCADA system. • Complex mathematical algorithms are only used for calculating flow based on wet-well levels and pump run times. • Visualization and understanding of the data uses conventional SCADA graphics, showing pumps on/off. • The system is primarily used in day-to-day operations for visual monitoring of the pump stations and for alarming. • The system is a stand-alone system.
EXAMPLES OF USE	The system is routinely used to monitor pump stations remotely. There have been instances where the SCADA system was used to prevent an overflow, because of early reporting of an issue at a pump station, which enabled an operator to respond to the issue. A simple example of this is a power outage. During wind events, the SCADA system will report where there is a power outage, enabling operators to bring portable generators to the pump stations to avoid an overflow.
LESSONS LEARNED	–
ADDITIONAL INFORMATION	–

City of Atlanta Department of Watershed Management (Atlanta, Georgia)

Image: Provided by City of Atlanta Department of Watershed Management

SEWERSHED INFORMATION

CUSTOMERS:	1.2 million
CONNECTIONS:	150,000
AREA:	132 sq. miles
GRAVITY:	300 miles combined 1,575 miles sanitary

CHALLENGES	Updating the model with survey data and as-built data
MONITORING GOALS	• Consent decree requirements • Hydraulic model calibration • Sanitary and combined system optimization and effectiveness
SENSORS AND PARAMETERS	• Level • Flow • Velocity • Temperature (15 min interval reading) • Rainfall city rain gauges and USGS rain gauges
SENSOR MANUFACTURERS	ISCO meters 2110, 2150, 2160, signature series, ultrasonic, transit time and flumes (Parshall, etc.)
SENSOR LOCATIONS	Temporary meters have been placed at the exit of each sewershed, and permanent meters have been placed along the big outfalls and trunks for model calibrations. Interjurisdictional meters are in sanitary pipes from adjacent cities and counties for billing purposes.
COMMUNICATIONS	• Locations inside utility facilities use a 4-20 analog signal. • Locations that are remote from facilities use cellular or radio.
ANALYTICS/USER INTERFACE/VISUALIZATION	• Flowlink, Foxboro City analytical platform and data visualization tool. • Third-degree polynomial and comparative analytics from historical observed versus reported.

	• Flow, velocity, level, rainfall and remote camera weather are used. • The system is used in day-to-day operations for SSO mitigation, pollutant tracking, sanitary sewer model, water quality, pressure, and voltage. • The system is standalone with a link to other systems such as United States Geological Survey (USGS) data capture to Department servers and output to a management analytical dashboard and wet weather mobile platform.
EXAMPLES OF USE	• Provide alert reports for mobile viewer. • Divert sewer spills; minimize volume of spills. • Build historical profile on a site.
LESSONS LEARNED	More improvements are underway to increase the accuracy and efficiency of the model building, calibration, and capacity-relief project evaluation process. In the upcoming years, the model will continue to be a tremendous asset in achieving Consent Decree deadlines. The model will be a resource for the design of capacity-relief projects to identifying the amount of flows that can be attributed to the six inter-jurisdictional municipalities that feed into the sanitary system.
ADDITIONAL INFORMATION	• Watershed approach to remote monitoring • Green infrastructure monitoring sites • Weather forecasting for flood warning and spill mitigation

City of Casper (Casper, Wyoming)

Image: https://en.wikipedia.org/wiki/Casper,_Wyoming#/media/File:Casperskyline.jpg

SEWERSHED INFORMATION

CUSTOMERS:	21,691
CONNECTIONS:	21,691
AREA:	24 sq. miles
GRAVITY:	316 miles
PRESSURIZED:	2.5 miles
SEWER TYPE:	Sanitary

CHALLENGES	• Aging infrastructure • Using a telephone communication method for remote lift/meter stations to the SCADA system at WWTP (reliability issues) • Security concerns of remote communications
MONITORING GOALS	• The goal of the meter stations is to properly bill non-Casper municipalities that send their wastewater through Casper's sewer network for treatment at the WWTP. • The goal of monitoring hydrogen sulfide (H_2S) is to identify conditions that will cause corrosion of a sewer interceptor. • The City of Casper has a facility that injects ferrous chloride into an interceptor sewer to control H_2S generation. The City monitors H_2S in an interceptor manhole just upstream of the WWTP to gauge effectiveness of ferrous chloride feed rates. Based on the H_2S measurements, the feed rate of ferrous chloride is adjusted.
SENSORS AND PARAMETERS	• Flow • H_2S

SENSOR MANUFACTURERS	• Flow rate is measured by Siemens Milltronics OCM II, OCMIII, or Siemens Sitrans LUT400 ultrasonic open channel flow monitors. The Milltronics monitors are older technology and are being replaced with Sitrans monitors. Compatibility and ease of operation are the reason for selecting Sitrans for replacement flow meters. • H_2S concentration - Odalog sensor. Recommended by CH2M following pilot study. City staff selected a model that had a range from 0-100 ppm as uncontrolled historic ranges of H_2S were usually less than 100 ppm.
SENSOR LOCATIONS	• Flow meters are installed on sewer interceptor lines at boundaries between municipalities. This enables billing for wastewater contributions by each municipality. Sometimes wastewater from Municipality A travels through Municipality B before getting to Casper, so the difference is calculated for the wastewater coming from Municipality A into Municipality B for Municipality B's bill. • The Odalog is located in a manhole on the main interceptor that is being treated with ferrous chloride. Specifically, it is located in a manhole very close to the WWTP to ensure that the entire interceptor is protected from corrosion and that the ferrous chloride has completely reacted before entering the WWTP (both over- and under-dosing are undesirable).
COMMUNICATIONS	• Data from flow meters are conveyed to the WWTP's SCADA system via telephone lines. • Control of the ferrous chloride inject rate can be controlled via the SCADA system (phone lines), but H_2S data collection from the Odalog is manually downloaded from the instrument while in the field.
ANALYTICS/USER INTERFACE/ VISUALIZATION	• Flow metering data are accessed completely through the SCADA system; the SCADA system graphs the data and provides totalized flow data. Staff monitor the flow to identify anomalies; if the data are not consistent with historic results, then the City confirms that the meter is calibrated correctly or try to identify why flow has increased. The system is stand-alone. • At this point, the single monitoring point for H_2S data will be downloaded from the monitor to a computer. It will likely be graphed and the ferrous chloride injection rate will be adjusted accordingly. It does not use algorithms or link to other systems.
EXAMPLES OF USE	• The metering network saves money on a routine basis as it allows the City to accurately bill other municipalities; sometimes customers' sump pumps are tied into the sanitary sewer and the City receives more wastewater than purchased, so municipalities are billed for all wastewater treatment independent of the source. • The ferrous chloride system will save infrastructure repair costs in the long term; some manholes and mains will need to be lined/coated, but the infrastructure should not have to be replaced in the foreseeable future.
LESSONS LEARNED	• The flow meter network was selected and installed decades ago, in most cases. It is costly to upgrade meters and associated communications equipment. It is also costly and risky (security) to use different communication methods.

	• The H_2S monitoring is just in its infancy, so there have not been lessons learned, yet. Maintaining clear documentation with photos of the site and making the documentation and any updates available to users on a common platform is important to answer questions regarding data or site settings.
ADDITIONAL INFORMATION	–

City of Escondido (Escondido, California)

Image: Provided by SmartCover

SEWERSHED INFORMATION

CUSTOMERS: 150,000

CONNECTIONS: –

AREA: –

GRAVITY: 370 miles

CHALLENGES	Potential spills
MONITORING GOALS	Early warning of potential spills
SENSORS AND PARAMETERS	Level
SENSOR MANUFACTURERS	SmartCover
SENSOR LOCATIONS	33 locations in the sewershed, including all lift stations
COMMUNICATIONS	Satellite (Iridium)
ANALYTICS/USER INTERFACE/ VISUALIZATION	SmartCover website
EXAMPLES OF USE	Early detection of backup during rainstorm prevented a sewerage spill and helped to identify a 24-inch collapsed pipe, saving the City millions of dollars in fines and repairs.
LESSONS LEARNED	–
ADDITIONAL INFORMATION	–

City of Los Angeles Bureau of Sanitation (Los Angeles, California)

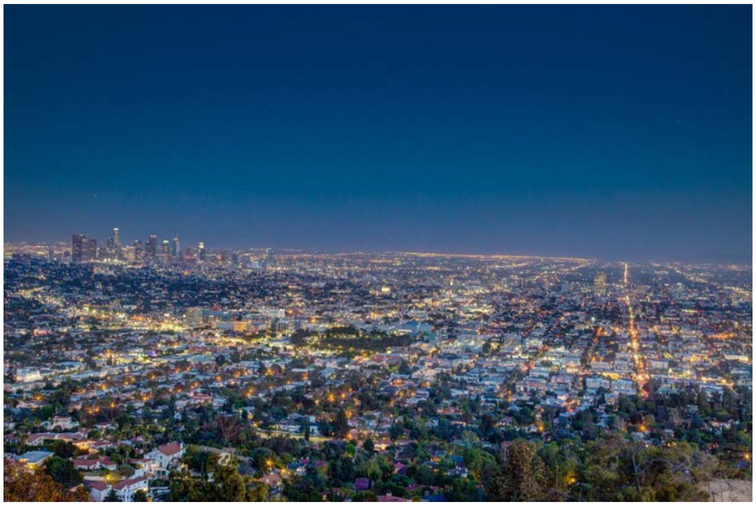

Image: Provided by Hach

SEWERSHED INFORMATION

CUSTOMERS:	4 million
CONNECTIONS:	~600,000
AREA:	~500 sq. miles
GRAVITY:	6,620 miles

CHALLENGES	• Existing infrastructure condition assessment and capacity assurance due to growth and changes in water conservation trends. • Obtaining timely high-water level alerts at critical locations of the conveyance systems.
MONITORING GOALS	• Collect data for revalidation of existing collection system flow and capacity model. • Provide ongoing monitoring for potential issues in the collection system and for capacity assurance. • Provide support during wet weather operations by providing near-time data and visual aids.
SENSORS AND PARAMETERS	• Fluid level and velocity are measured in the collection system and used to calculate flow, sometimes level-only is measured for sites with simple hydraulics.
SENSOR MANUFACTURERS	• In conjunction with Hach FL900 logger • Hach Flo-Dar Area/Velocity Radar Flow Meter with Surcharge Velocity Sensor (the Flo-Dar is the primary sensor and the data from it is most typically used) • Hach Sub-AV with AV9000 sensor (as needed for • Hach US9001 down-looking sensors (as needed for redundancy based on site conditions) • Hach US9003 in-pipe sensor (as needed for redundancy based on site conditions) • Appropriate antenna selection for site conditions

	redundancy based on site conditions)
SENSOR LOCATIONS	Measurements are taken at key locations (~100-120 sites) throughout the collection system. These sites are monitoring continuously. Typically, the locations selected are on the major outfalls/trunks and interceptors. These locations were selected based on the following reasons: (1) to calibrate the hydrodynamic model and (2) to provide a "pulse" for the system in day-to-day and wet weather operations so that issues are easily identified and can be resolved. Other sites (~50) are rotated on an annual basis for the purpose of collecting data in selected basins to establish RDI/I relationships during wet weather events.
COMMUNICATIONS	All monitoring locations are at remote sites in maintenance holes (not within utility pumping or reclamation facilities). As such, all sensors are battery powered and communicate via cellular modem with a central server for meter programming, data transfer, and alarming.
ANALYTICS/USER INTERFACE/ VISUALIZATION	• Data visualization and analysis is done through a third-party web platform called FlowWorks. • Sensors: Both the Hach Flo-Dar sensor and Hach SubAV sensor with the AV9000 Analyzer Module use complex mathematical algorithms to calculate flow from received inputs. • Analysis platform: The FlowWorks platform contains an application called FACE that allows the use of complex mathematical algorithms for real-time data analysis. • Visualization and review of the data are done in FlowWorks. The platform provides a map view and graphing functionalities that allows City staff to quickly visualize the gauging locations on a map in the context of the collection system (through a GIS layer). • The data are not used in any specified day-to-day operation. However, a daily review is performed to ensure that the sites are functioning as anticipated and no high-level alarms require any action. • At the moment (2017), there are no direct connections to maintenance planning systems or weather forecasting sites. However, the Bureau does have a dashboard on the FlowWorks platform that provides operational insights for rapid response during wet-weather events.
EXAMPLES OF USE	The gauging network, as it exists now (2017), is used to monitor the status of the collection system during wet-weather events. Being able to monitor the network in near real-time allows Bureau staff to receive notifications regarding the pipe and trunk status (ok, full, surcharging) in order to make decisions regarding storage to prevent any spills during

	wet weather alerts. In the past, the gauging locations have also revealed unexpected issues or high-level situations that allowed for the notification of maintenance staff to take corrective actions.
LESSONS LEARNED	• Selection of gauging locations is key. It is important to make sure that the location is hydraulically suitable and there are no unforeseen obstacles. A good pipe inventory and a (at a minimum) topside field investigation is necessary to get quality data. Topside conditions should also be of concern when developing a network because traffic patterns or traffic control restrictions could prevent the installation of a gauging location. • Consider the use of redundant sensors in critical locations. For example, a backup level sensor can provide a source of data until a failed primary sensor is serviced. • Understanding the limitations of the technology is important. For example, during adverse weather conditions or other physical barriers (such as a car parked over a maintenance hole), data may not be sent via the cellular network. Placement of meters and any associated telemetry should be considered if the gauging location is critical. • Revalidation of gauging locations is crucial in maintaining data quality. Putting all gauging sites on a regular revalidation schedule will help establish confidence in the data that is collected over a long period of time. • The relationship between the flow monitoring provider and the utility implementing the program is key. Setting clear expectations and checking in on a regular basis to discuss higher level goals is important to ensure all parties are on the same page. Experienced field personnel are able to assist the utility in making sure that proposed locations are acceptable for gauging. • Alarms and notifications set at gauging locations need to be checked periodically to avoid as many false alarms as possible. This builds trust in the technology for when a true actionable event is observed. • Maintaining clear documentation with photos of the site and making the documentation and any updates available to users on a common platform is important when answering questions regarding data or site settings.
ADDITIONAL INFORMATION	–

Los Angeles County Sanitation Districts (Los Angeles, California)

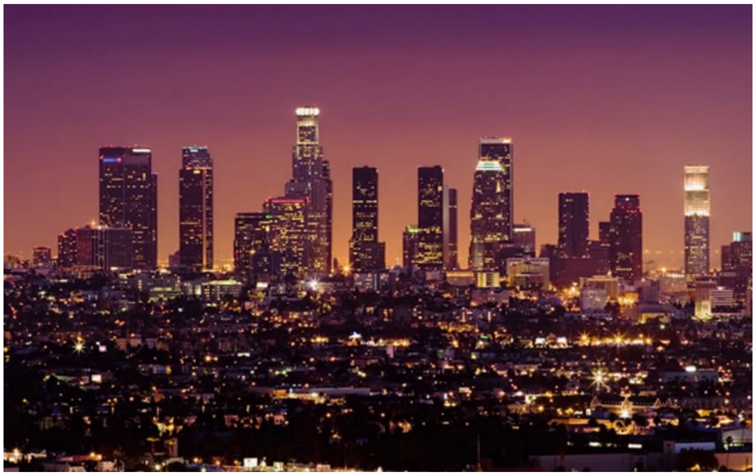

Image: http://cdn.wonderfulengineering.com/wp-content/uploads/2016/01/Los-Angeles-Wallpaper-37.jpg

SEWERSHED INFORMATION

CUSTOMERS:	73 cities and unincorporated territory
CONNECTIONS:	–
AREA:	850 sq. miles
GRAVITY:	~1.300 miles

CHALLENGES	• Aging infrastructure • Staff training and development • Inflow and infiltration • Preventing overflows
MONITORING GOALS	• Preventing overflows • Identifying and prioritizing capital improvement projects • Optimizing program • Saving money
SENSORS AND PARAMETERS	• Level • Flow
SENSOR MANUFACTURERS	• Various flow meters, both level only and area velocity meters • HACH • ADS • SmartCover • USCubed
SENSOR LOCATIONS	Locations can be selected based on historical information such as past location of overflows, projected capacity concerns due to increased development or projects, critical junction structures to determine flow split, or upstream of treatment plants or pumping plants.
COMMUNICATIONS	Both hard-wired sensors connected to the SCADA system and remote sensors using cellular or satellite transmission that can be viewed from a third-party website are used.

ANALYTICS/USER INTERFACE/ VISUALIZATION	• Both the SCADA system and third-party websites are used. • Some websites use mathematical algorithms to determine trends and trigger alarms. • Usually location of sensor, flow data and other physical information such depth, pipe size, etc. are provided for visualization. • In day-to-day operations, alarms are used to trigger investigations and possible response measures, understand system-wide capacity, determine hydraulic grade line during storm events, identify impacts to treatment plants, etc. • The sensors are stand-alone, but the information is processed by staff and used for other systems.
EXAMPLES OF USE	• Saved money in a critical situation – Remote level sensors have provided real-time information during storm events, aiding staff in operating pumping plants to prevent overflows. • Saved money in routine operations – Remote level sensors have eliminated the need to deploy staff on a regular basis to check sewer condition.
LESSONS LEARNED	–
ADDITIONAL INFORMATION	–

May Caramel (Haifa, Israel)

Image: https://upload.wikimedia.org/wikipedia/commons/4/4b/Haifa_Bay.JPG

SEWERSHED INFORMATION

CUSTOMERS:	~120,000
CONNECTIONS:	~270,000 residential 1,000s business, government, etc.
AREA:	60 sq. kilometers
GRAVITY:	~455 kilometers

CHALLENGES	May Carmel is responsible for more than 1,200 km of pipes (water and wastewater) and more than 100 pump stations. This is the most complicated water and wastewater network in Israel and combines a large residential area with a few industrial zones, some with very heavy industries. The city is located on a high mountain with extreme elevation differences. Additionally, the city has a very long coastline and experiences sea water infiltration.
MONITORING GOALS	The main goal of May Carmel is to create a “smart wastewater network” that will allow them to actually have full visibility of what is currently in the pipes and allow better real-time control to save operational expenses and support better enforcement tools and processes.
SENSORS AND PARAMETERS	• Ultrasonic level meter • ORP • Temperature • pH • Conductivity
SENSOR MANUFACTURERS	• Aqualubo • Ponsel
SENSOR LOCATIONS	• In general, locations are selected to provide the most effective coverage of the utility assets. • Common locations are factory discharge manholes, main collector manholes, pump stations, and WWTP. • Selected industry outputs locations. • Collection lines. • Pumping stations. • Lower altitude locations.

COMMUNICATIONS	2G/3G cellular connection
ANALYTICS/USER INTERFACE/ VISUALIZATION	• User interfaces are developed specific to the utility and can be connected to any SCADA or third-party's dedicated system. • Several layers of complex mathematical algorithms are used to identify polluted streams, pinpoint the polluter, and optimize the response for the event. Algorithms access several databases to perform a correlation between the measured parameters and then calculate a "pollution index." To locate the upstream polluter, pattern recognition and other statistical methods are used. Optimization algorithms are used to improve the response (such as activation of a sampler). • Visualization depends on the client role: it varies from graphs with raw data or calculated data (such as the pollution index) to tables, pie charts, and other infographics available on a desktop or mobile device. Push notifications are also used to inform the client about specific alerts or important insights. Automatic weekly and monthly visual reports give the client the information it needs about the sewer network. • The system is stand-alone. However, it can be connected to any third-party database (online/offline) using an application programming interface (API), for example, weather forecasting sites.

EXAMPLES OF USE	• Saved money in a critical situation:
	  • A dramatic reduction if the WWTP process collapses
	  • Within a few months of installation of the system, the overall load coming to the WWTP was reduced by double-digit percentages, which helped avoid the need to upgrade the WWTP
	• Saved money in routine operations:
	  • Increased the lifetime of pipes
	  • Reduced the operational costs of the WWTP
	  • Reduced the daily use and number of sewage tracks

LESSONS LEARNED	• The utility was able to identify the relevant collection pipes with the highest pollution and trace upstream to identify the polluting factories. • May Carmel was able to work with the relevant factory to implement changes to reduce the pollution. • The utility was able to build a smart pipe replacement program and reduced the number of sewage tracts.
ADDITIONAL INFORMATION	–

Metropolitan Sewer District of Greater Cincinnati (Cincinnati, Ohio)

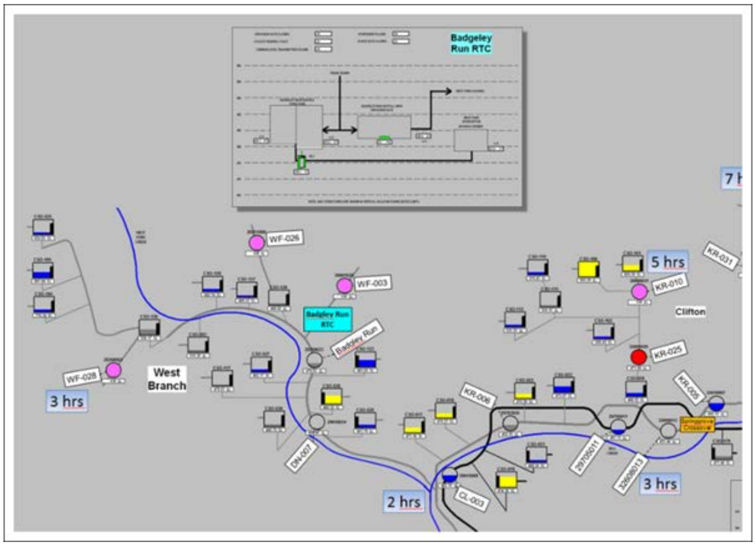

Image: Provided by MSDGC

SEWERSHED INFORMATION

CUSTOMERS:	226,000
CONNECTIONS:	–
AREA:	290 sq. miles
GRAVITY:	641 miles
RESSURIZED:	19 miles

CHALLENGES

The Metropolitan Sewer District of Greater Cincinnati (MSDGC) has one of the most challenging collection systems in the country to manage during wet weather as it contains more than 200 combined sewer overflow points. Together these overflows discharge over 11 billion gallons of sewage into the Ohio River and its tributaries during a typical year. The utility is under two consent decrees to reduce these overflows, with the cost of compliance exceeding $3.2 billion. With sewer rate increases over the last 10 years bringing the typical household's bill close to the limits of affordability, MSDGC was driven to find new ways that were less costly to address its wet weather challenges.

Field sensors (in-pipe and in-stream) form the underpinning of the District's Smart Sewer System, so the search for the equipment most suitable for this application was a focus of tremendous effort. Much of the installed equipment needed to serve multiple purposes. For instance, level sensors installed for operational purposes are also used for regulatory reporting at all overflows (CSOs, SSOs) and specialized "dual sensor" units were needed at locations that are impacted by river intrusion during high-water conditions. Many of the locations monitored in the SCADA system also collect data used by the hydraulic model for project planning and post-construction validation, so the equipment needed to provide data in real-time as well as reliably over the long term. Finally, the monitoring needs of MSDGC continue to expand, with the inclusion of the rain gage network into the SCADA system, the odor sensors being deployed near pump stations for early detection of H_2S, and future needs for water quality sensors at key

	locations in the watershed. Legacy equipment was expensive to maintain, posed security concerns if integrated into a remote monitoring via the internet, and was not interoperable with the SCADA system. Therefore, multiple pilots were conducted and, ultimately, a competitive bid was advertised. Selection criteria primarily focused on internet-protocol (IP)-based wireless communication capabilities, the ability to be integrated directly into the SCADA system, and data encryption capabilities, as well as features such as configurable sampling rate, the ability to backfill data when communication is lost, optimal operating ranges for level sensors, optimal battery life, and interchangeable sensor options.
MONITORING GOALS	• Real time visibility of wastewater system • Maximize storage, conveyance, and treatment capacity
SENSORS AND PARAMETERS	• Level • Flow • Pressure
SENSOR MANUFACTURERS	• Ayyeka • Flowshark • Isco • Nile (radar)
SENSOR LOCATIONS	• Monitoring equipment at 650 locations. • By the end of 2017, its Smart Sewer System will extend over all combined-sewer areas of the MSDGC collection system, incorporating three major treatment plants, nine wet weather storage and treatment facilities, eight major interceptor sewers, all 276 overflow points, 27 rain gauges and seven river level sites.
COMMUNICATIONS	Secure cellular telemetry
ANALYTICS/USER INTERFACE/ VISUALIZATION	–
EXAMPLES OF USE	The long-term goal of the system is to maximize the storage, conveyance, and treatment capacity of the wastewater system during wet weather. While still early in its deployment, benefits of the system have already been demonstrated. Remote monitoring has improved the maintenance of wet-weather facilities, and remote control of facilities enables quicker response to extreme events. At the end of 2016, MSDGC quantified that these new capabilities provided by the dedicated wet weather SCADA reduced overflows from the collection system an average of 400 million gallons per year, at a cost of \$0.01/gallon. Compared to a cost of \$0.40/gallon to store and upwards of \$1.00/gallon to treat this overflow volume, the SCADA system is proving to be a very cost-effective investment. In addition, several unanticipated benefits have been uncovered. Treatment plant operators, whose view was previously limited to within the treatment plant, began "seeing" the collection system for the first time. Plant

	operators now have timely information with which to bring additional equipment online "just-in-time" based on a developing storm and adjust influent gates during periods of river intrusion. Further, specialized alerts generated by the system enable a large industrial customer to adjust its discharge of high-strength waste during specified wet-weather conditions, reducing the threat of release to the environment.
LESSONS LEARNED	–
ADDITIONAL INFORMATION	Altogether, the smart sewer network enables MSDGC to optimize the use of existing infrastructure in real-time so that fewer and smaller facilities need to be built in the future, reducing the capital investments needed to comply with the next phase of the consent decrees by tens of millions of dollars. A real-time window into the collection system during wet weather has also exposed the underutilization of interceptor sewers as rainfall is often spatially varied. The upsizing of CSO underflow pipes and the addition of automated control gates that are integrated into the wet-weather SCADA system are planned as future cost effective wet-weather solutions that further leverage the capabilities of a smart sewer network.

Seattle Public Utilities (Seattle, Washington)

Image: https://upload.wikimedia.org/wikipedia/commons/b/b7/Seattle_Skyline_tiny.jpg

SEWERSHED INFORMATION

CUSTOMERS:	652,000 residential 64,000 business
CONNECTIONS:	716,000
AREA:	84 sq. miles
GRAVITY:	1,000 miles combined 450 miles sanitary

CHALLENGES	• Sewer overflows • Consent decree • Upgrade pump facilities • Building a new pump station
MONITORING GOALS	• Managing our system as efficiently as possible. • Using data to modify operations to maximize storage and optimize pumping. • Providing accurate and timely reporting to meet Seattle Public Utilities (SPU's) CSO National Pollutant Discharge Elimination System (NPDES) Permit requirements. • Provide timely response to system problems. • Inform maintenance activities.
SENSORS AND PARAMETERS	• Level • Flow • Temperature • Conductivity • pH • 16 rain gauges
SENSOR MANUFACTURERS	• Ultrasonic – Pulsar, Siemens • Radar – Rosemount • Pressure – KPSI, Druck • Area Velocity Flow Meter (AVFM) – Greyline • Continuous water quality and level sensors – In situ
SENSOR LOCATIONS	Monitoring sites are selected depending on the application. For CSO facilities and pump stations, monitoring equipment is located at the facilities for operational purposes. Sensors are located in wet wells, flow control structures, storage tanks/pipes, overflow manholes, and mainline pipes depending on the operation of each facility. SPU has recently constructed real-time control CSO facilities that require data to monitor the system to control the automated gates/valves that

	regulate flow. Sensor locations are selected based on the design of each facility and at locations in the system that are suitable for system monitoring, avoiding areas with challenging hydraulic conditions. For NPDES overflow reporting, sensors are installed in the overflow structures to monitor CSOs to our NPDES outfalls. For temporary flow monitoring, sensors are located throughout the system to provide data to information for modeling analysis.
COMMUNICATIONS	• Unlicensed spread-spectrum radio • Wired Ethernet (copper and fiber)
ANALYTICS/USER INTERFACE/ VISUALIZATION	• The DWW system data comes from several sources. A SCADA system provides 24/7 monitoring for 68 wastewater pump stations and selected CSO storage facilities. In addition, a third-party vendor (ADS) monitors the remaining CSO outfalls. • Algorithms are used to calculate pumping rate at pump stations that do not have flow meters. • WonderWare is the platform used. The program allows SPU to trend tags to visually analyze the data. • SPU has a 24/7 control center that monitors data from the SCADA system. Alarms are received and crews are dispatched if required. In addition, a group within SPU monitors the data to determine how facilities are performing. Staff perform data screening and analysis weekly to inform maintenance of assets as well as changes to facility operations. • An IMS system houses data from multiple sources. The SCADA system does not link to the computerized maintenance management system. A separate management dashboard that is not automatically linked uses downloaded SCADA data for analysis.
EXAMPLES OF USE	• Time series data are used regularly to screen for maintenance issues in the CSO and pump station facilities. This regularly prevents overtime call outs or overflows based on what is observed in the data. • Real time data are used regularly as an early warning system to prevent dry weather overflows. Crews are dispatched regularly to investigate issues in the system that could lead to non-compliance. • Time series data are used to assess the performance of facilities and make adjustments to ensure that storage and pumping is maximized. Monitoring data are also used to evaluate whether there can be further optimization of the operation of existing facilities. The system is currently in the analysis phase and, therefore, examples of implemented operational optimization are not available at this time.
LESSONS LEARNED	–
ADDITIONAL INFORMATION	–

South Bend Indiana Department of Public Works (South Bend, Indiana)

Image: Provided by EmNet

SEWERSHED INFORMATION

CUSTOMERS:	40,064
CONNECTIONS:	40,064
AREA:	40 sq. miles
GRAVITY:	641 miles
RESSURIZED:	19 miles

CHALLENGES	The City of South Bend has a combined sewer system with an interceptor and underflow lines designed to carry only the maximum dry weather flow. Therefore, prior to 2008, virtually every time it rained in South Bend, the sewers would overflow into the Saint Joseph River, normally one to two billion gallons or more annually. The City typically reported 25 to 30 dry weather overflows each year as well. In 2011, South Bend entered into a consent decree with U.S. EPA Region 5 and the U.S. Department of Justice, agreeing to a long-term control plan estimated in today's dollars to be roughly $860 million. The City has 101,735 residents and a median household income of $34,656.
MONITORING GOALS	In 2008, the City implemented a distributed sensor network of 120+ level sensors, flow meters, and rain gauges. The objective of this program was to begin studying the collection system to design a coordinated real-time control and decision support system (RT-DSS). In the process, the City and EmNet used the data to turn on the lights in the collection system, which immediately pointed to a long list of issues that needed to be fixed, including river intrusion, blockages, grit deposition, bottlenecks, sagging lines, and under-performing river crossings. Through data analytics and visualization, the City was able to address all of these issues in short order, eliminating its dry weather overflow problem and creating new found wet weather capacity as well. In late 2011 and early 2012, South Bend installed and commissioned a coordinated real-time control system utilizing newly installed auxiliary underflow or throttle lines that were twice the diameter of the existing throttle lines at nine of the City's 36 CSO regulators. Each new throttle line added four times the flow capacity, which were controlled with pinch valves and managed by computer agents co-located in PLC cabinets at each site. All

	nine control agents talk to each other every five minutes to assess upstream and downstream conditions and to buy and sell conveyance and treatment capacity using a market-mimetic framework of agent-based optimization. Today South Bend's RT-DSS comprises 151 sensor locations and manages flow at 13 RTC sites, including eight of the original nine (one was removed when the CSO structure was closed). South Bend has eliminated dry weather overflows and reduced wet weather overflows by roughly 75%.
SENSORS AND PARAMETERS	• Level • Flow • ORP • Turbidity • Temperature • Precipitation
SENSOR MANUFACTURERS	• Teledyne Isco • Global Water
SENSOR LOCATIONS	• Depth upstream of every CSO regulator • Depth and flow along the interceptor to track hydraulic grade line, bottlenecks, and debris • Flow into the regulator chambers at the 20 largest overflow sites • Depth in major trunk lines, specifically at several maintenance hot spots and major model inflow points • Water quality sensors on Bowman Creek – an impaired stream • Roughly even distribution of rain gauges
COMMUNICATIONS	Remote: combination of 900 MHz radio mesh network and cellular modems (EmNet equipment)
ANALYTICS/USER INTERFACE/ VISUALIZATION	• The system uses a combination of EmNet-developed user interfaces and analytics tools (known commonly today as EmNet's BLU-X™ platform) as well as the SCADA system. • Complex mathematical algorithms are used. The total number of possible combinations of gate and valve positions to dynamically optimize flows is in the trillions. • Visualization is provided by EmNet's BLU-X platform (shown above) –a cloud-based, highly interactive data hosting site using standardized and bespoke visualization and analytics tools. • Day-to-day operations use BLU-X for engineering and the SCADA system and PLC HMIs for operators. • In this case the system is highly interactive with the SCADA system, but does require weather forecasts to operate effectively. • The system is stand-alone. However, it can be connected to any third-party data base (online/offline) using API (for example, weather forecasting sites).

EXAMPLES OF USE	• Saved money in a critical situation: o The City is reopening its consent decree with a newly proposed long-term control plan based on its success with RT-DSS. The new plan, if accepted, will save the City roughly $500 million. • Saved money in routine operations: o The City has reduced operations costs by roughly $1.5 million per year, including having detected and removed 10 to 12 MGD of river intrusion. • Prevented or mitigated a non-compliance situation: o BLU-X provides preventative maintenance warnings to operators for condition-based maintenance, from which the City has eliminated its dry weather overflow problem.
LESSONS LEARNED	• Engage operators openly and collaboratively as early on as possible. • If the client is managing sensor network, make sure it has a robust maintenance program with well-trained staff. • Engage engineers and operators to co-design the systems tools they will ultimately be using.
ADDITIONAL INFORMATION	–

APPENDIX C

Task 2 – Assemble Panel and Conduct Expert Workshop – Summary of Expert Workshop

Designing Sensor Networks and Locations on an Urban Sewershed Scale

Task 2 – Assemble Panel and Conduct Expert Workshop – Summary of Expert Workshop

PREPARED FOR:	Water Environment & Research Foundation
PREPARED BY:	CH2M
DATE:	May 11, 2018
PROJECT NUMBER:	SENG6R16

The plan for *Task 2 – Assemble Panel and Conduct Expert Workshop* of project SENG6R16 was to review and build on the findings of the survey results and case studies from Task 1 to identify the top industry sewershed challenges and potential use cases to address them. The consultant for the Water Environment and Research Foundation (WE&RF) Big Data research project (SENG7R16) also participated in the Expert Workshop. This Technical Memorandum summarizes the Expert Workshop and includes a list of attendees, the agenda, a copy of the slides presented, and a summary of the outcomes of the breakout session.

Attendees

Utilities and technology providers that had participated in the surveys or responded with a case study in Task 1 were invited to attend the Expert Workshop. A total of 48 people were invited, representing 22 utilities and 21 technology providers. In addition to the project team, 17 people attended, representing six utilities and eight technology providers. The list of attendees is presented in Attachment A.

Agenda

The agenda consisted of the following:

- Summaries of the results of the Sewershed and Big Data surveys
- Presentation of two case studies of complex intelligent systems at wastewater utilities
- Group discussions

The detailed agenda is provided as Attachment B.

A copy of the slides used for each of the sessions in the agenda is provided as Attachment C.

Breakout Session

The following two topics were identified for discussion in group settings:

- **Identify Internet of Things (IoT) Gaps in the Industry**
- **Identify Potential Use Cases**

The participants were asked to define the Top Five use cases for each topic.

A summary of the discussion points and outcomes is presented at Attachment D.

Summary/Conclusions

Attendees at the workshop included representatives from six utilities and eight technology providers. These representatives participated in breakout sessions where they were separated into two groups.

The first group's top five use cases were as follows:

6. Correlation between weather events and operational data to overflow events (an example of deep learning)
7. Driving more efficient asset management/failure prediction
8. Identification/prediction of nitrification within chloraminated systems and non-revenue water (NRW)
9. Real-time modeling driven by real-time sensor data
10. Advanced analytics for source water protection

The second group's top five use cases were as follows:

1. Dynamic silt monitoring/estimation
2. Sensor Placement Optimization
3. Sanitary Sewer Overflow (SSO) mitigation – use of a simple level sensor
4. NRW – using district metering areas (DMA)
5. Managing river/surface water quality

Attachments

A List of Attendees

B Workshop Agenda

C Workshop Slidepack

D Summary of Breakout Session Outcomes

Attachment A – List of Attendees

WE&RF Sewershed Expert Workshop – List of Attendees

	Attendee	E-mail	Organization
1	Ken Thompson – Co-PI	ken.thompson@ch2m.com	CH2M
2	Chris Macintosh	chris.macintosh@ch2m.com	
3	Raja Kadiyala	raja.kadiyala@ch2m.com	
4	Sandy Orren	sandy.orren@ch2m.com	
5	Walter Graf	wgraf@werf.org	WE&RF
6	Reese Johnson	reese.johnson@cincinnati-oh.gov	Metropolitan Sewer District of Greater Cincinnati, OH
7	Eric Habermeyer	Eric.Habermeyer@seattle.gov	Seattle Public Utilities, WA
8	Rasheed Ahmad	rahmad@atlantaga.gov	Atlanta Department of Watershed Management
9	Alberto Bechara	abechara@atlantaga.gov	
10	Patrick Woodall	pwoodall@atlantaga.gov	
11	Perry Holland	Pholland@mwrd.dst.co.us	Denver Metro Wastewater Reclamation District, CO
12	Barbara Wilson	bwilson@mwrd.dst.co.us	
13	Doug Rulison	drulison@auroragov.org	City of Aurora, CO
14	Elkin Hernandez	Elkin.hernandez@dcwater.com	DC Water
15	Miguel Molina	mmolina@hach.com	Hach
16	Brendt Thompson	bthompson@s-can.us	s::can
17	Kevin Simpson	kevin.simpson@xyleminc.com	Xylem, Inc.
18	Remy Marcotorchino	rmarcotorc@sierrawireless.com	Sierra Wireless
19	Chris Barringer	chris.barringer@hds.com	Hitachi Data Systems
20	Luis Montestruque	lmontestruque@emnet.net	Emnet
21	Kevin Shipp	kevin.shipp@optimatics.com	Optimatics
22	Gili Elkin	gili@ici.fund	Israeli – Colorado Innovation Fund

Attachment B – Workshop Agenda

Expert Panel:

Designing Sensor Networks and Locations on an Urban Sewershed Scale

October 6, 2016

Time	Topics of Discussion	Presenters/Participants
8:00 – 8:30	Continental Breakfast	All Attendees
8:30 – 8:45	Welcome from WE&RF	Walter Graf
8:45 – 9:00	Introductions	Ken Thompson
9:15 – 10:00	Urban Sewershed Monitoring Survey Findings	Chris Macintosh
10:00 – 10:45	Case Study: Cincinnati Metropolitan Sewer District	Reese Johnson
10:45 – 11:00	Break	All Attendees
11:00 – 11:45	Case Study: Lee Tunnel Project	Tyler Nading
11:45 – 12:30	Big Data Analytics Survey Findings	Raja Kadiyala
12:30 – 1:00	Lunch	All Attendees
1:00 – 1:30	Identify IoT Gaps in the Industry	Group Exercise
1:30 – 2:30	Identify Potential Use Cases and Report Out	Breakout Groups
2:30 – 3:00	Break	All
3:00 – 4:00	Define Top Five Use Cases and Report Out	Breakout Groups
4:00 – 4:30	Wrap-up and Overview	Walter Graf, Ken Thompson

Attachment C – Workshop Slidepack

Designing Sensor Networks and Locations on an Urban Sewershed Scale

Agenda

Time	Topics of Discussion	Presenters/Participants
8:00 – 8:30	Continental Breakfast	All Attendees
8:30 – 8:45	Welcome from WE&RF	Walter Graf
8:45 – 9:00	Introductions	Ken Thompson
9:15 – 10:00	Urban Sewershed Monitoring Survey Findings	Chris Macintosh
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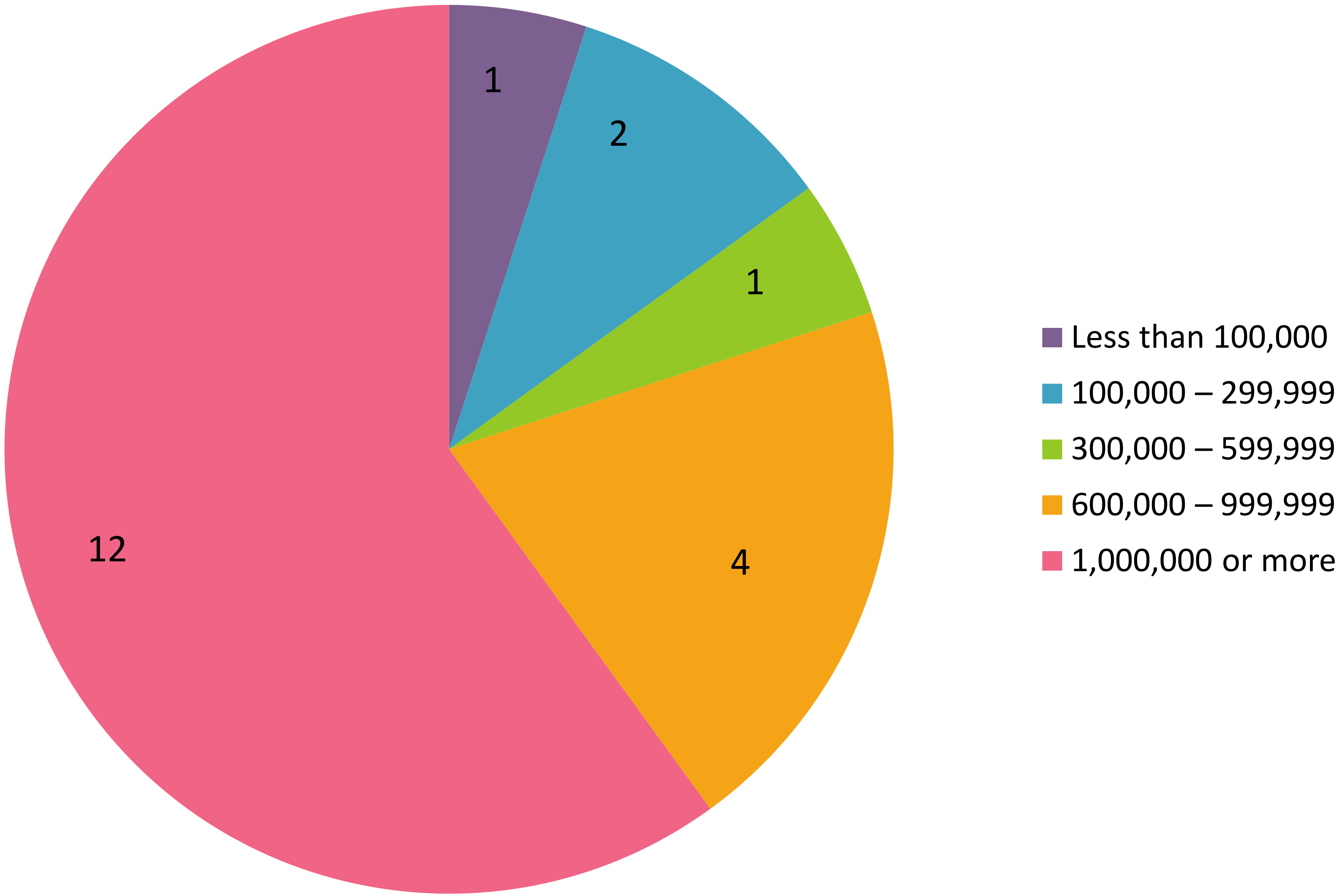
2:30 – 3:00	Break	All
3:00 – 4:00	Define Top 5 Use Cases and Report Out	Breakout Groups
4:00 – 4:30	Wrap-up and Overview	Walter Graf, Ken Thompson

Designing Sensor Networks and Locations on an Urban Sewershed Scale - Survey Findings

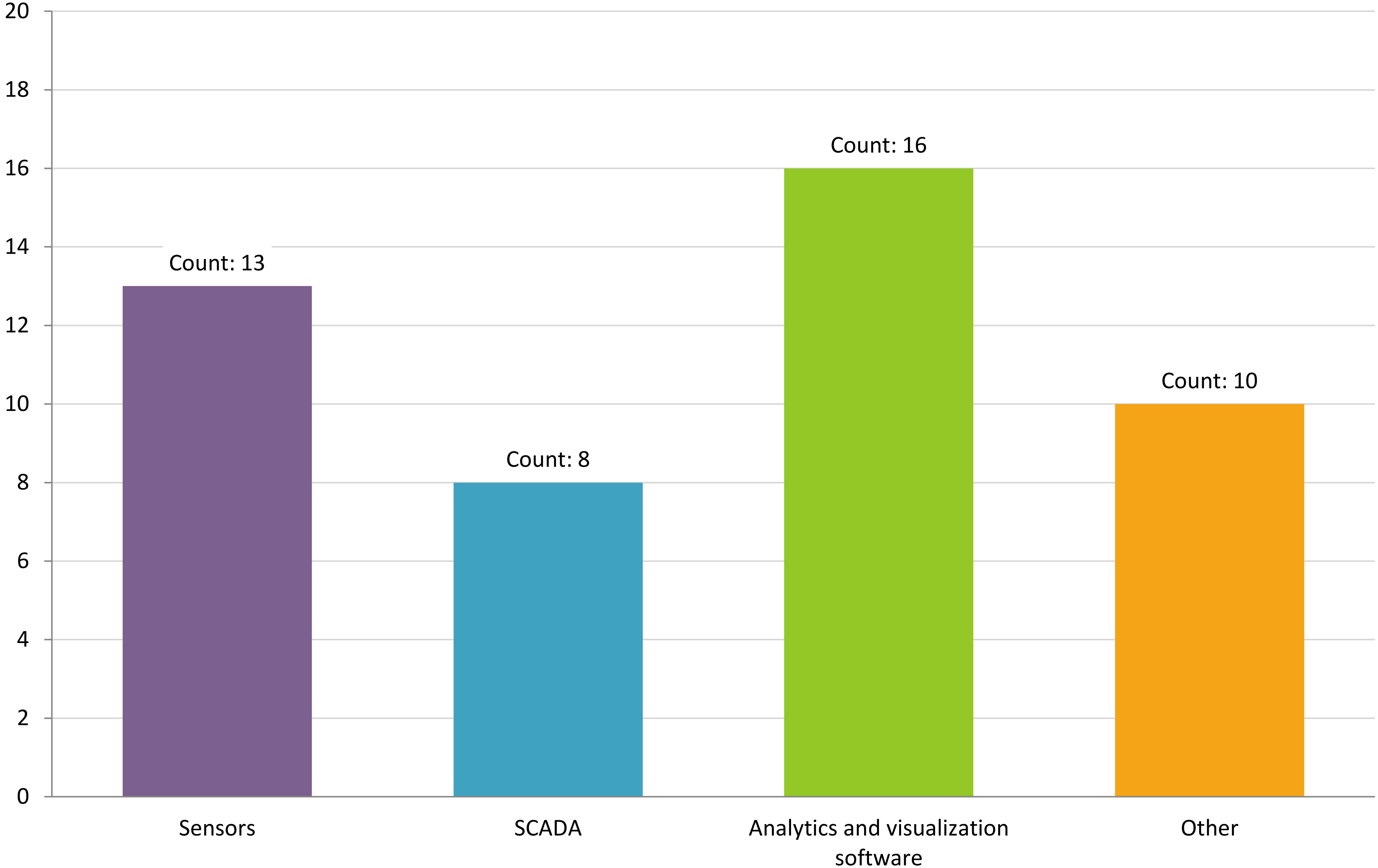
Survey Participants

- **20** Utilities:
  - 16 from US (representing 9 states), 2 from Europe, 1 South America, 1 South-East Asia
  - 30 questions in the survey
- **20** Technology Providers:
  - 27 questions in the survey

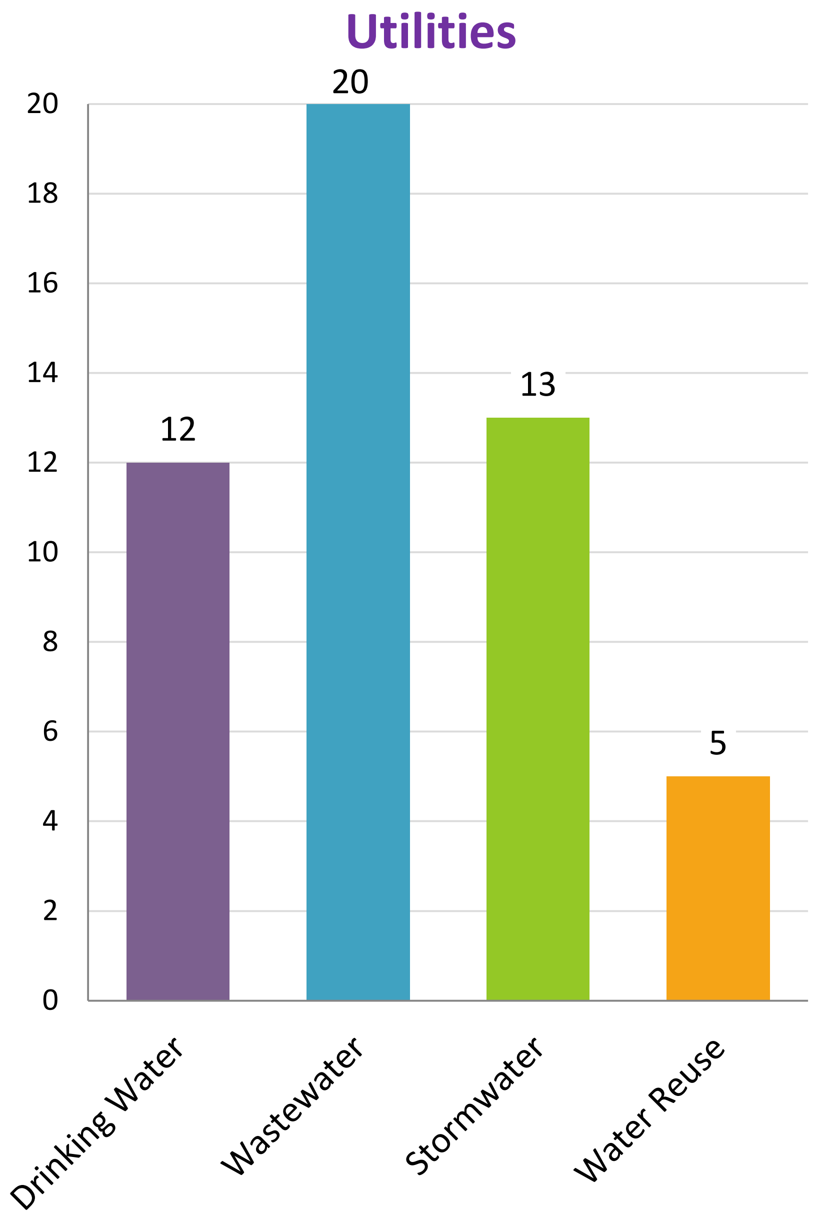
What population does your utility serve?

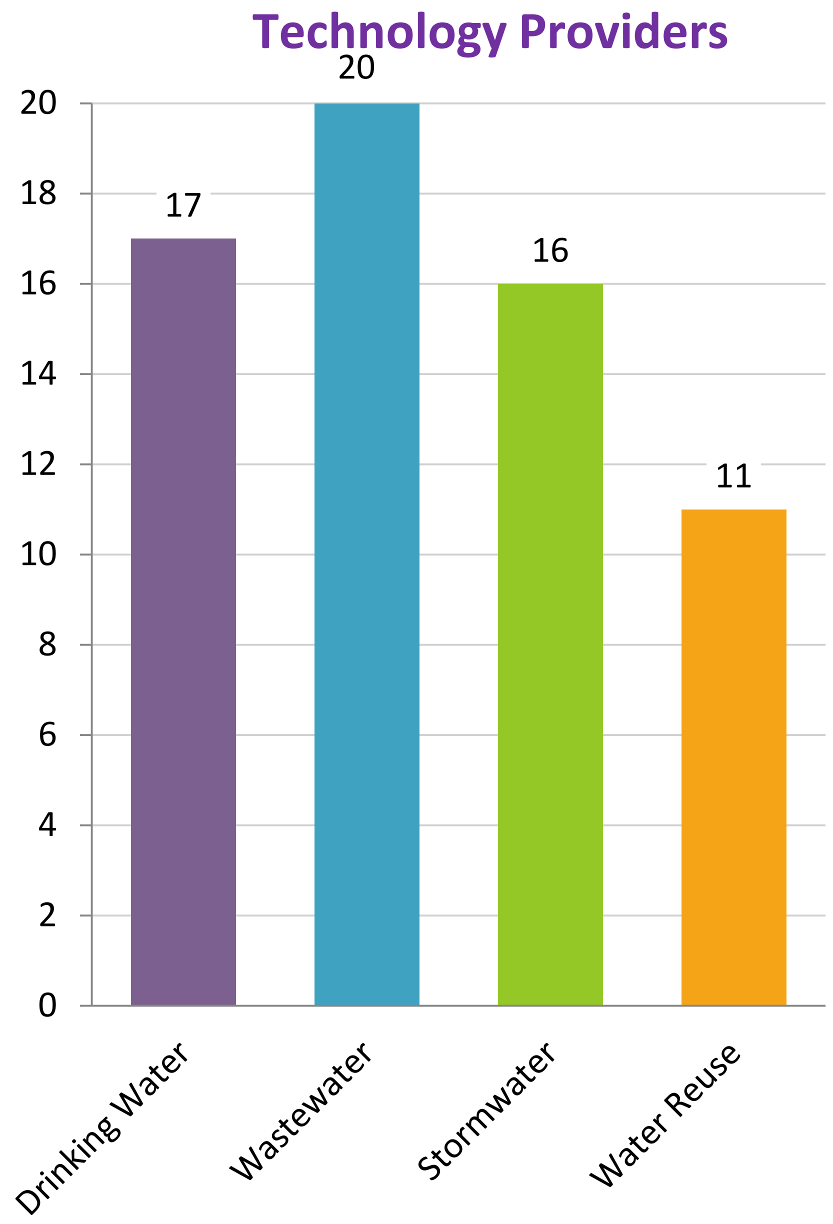


What technologies does your organization supply to water and wastewater utilities? Please select all that apply.

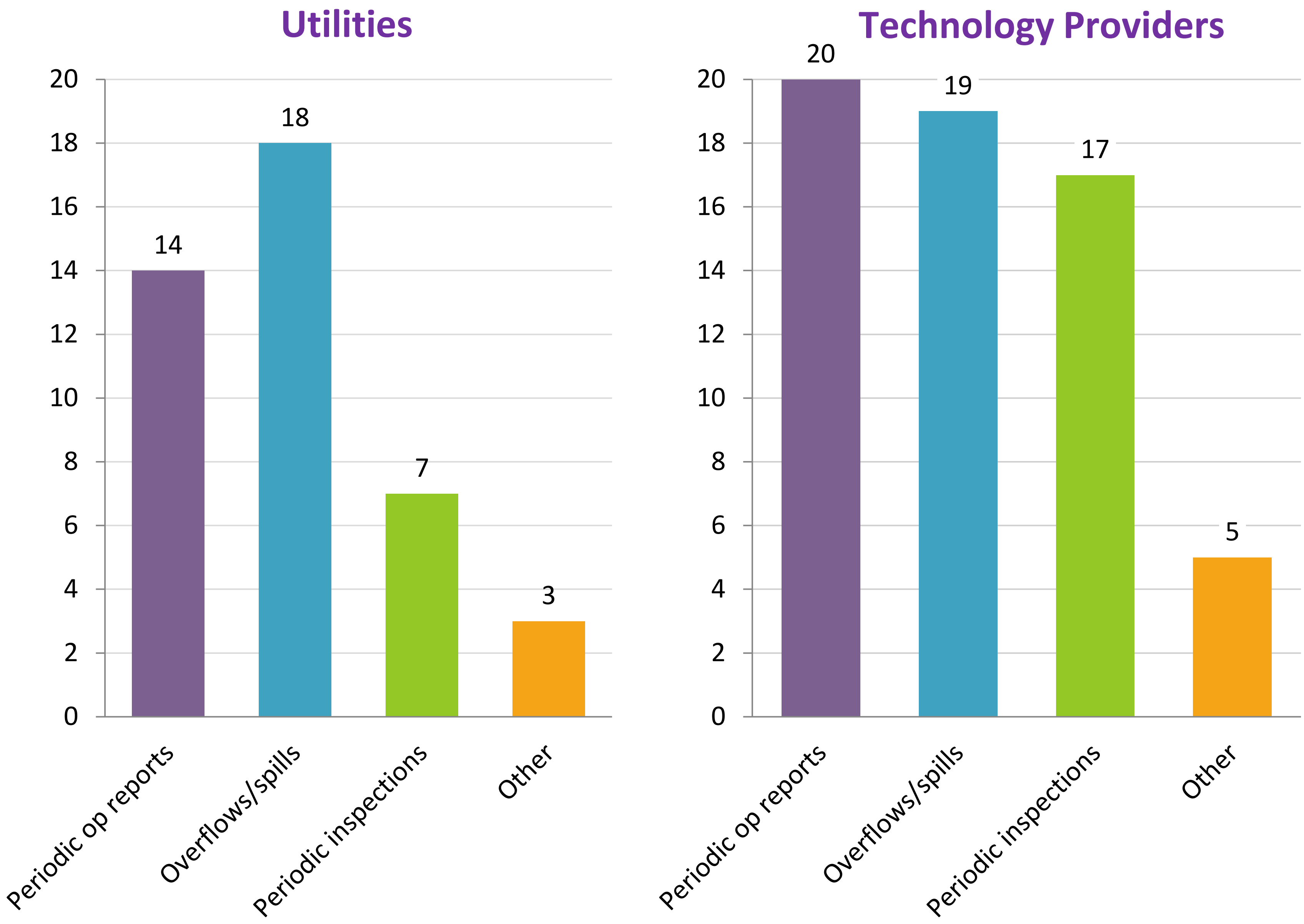


What types of facilities does your utility currently manage?

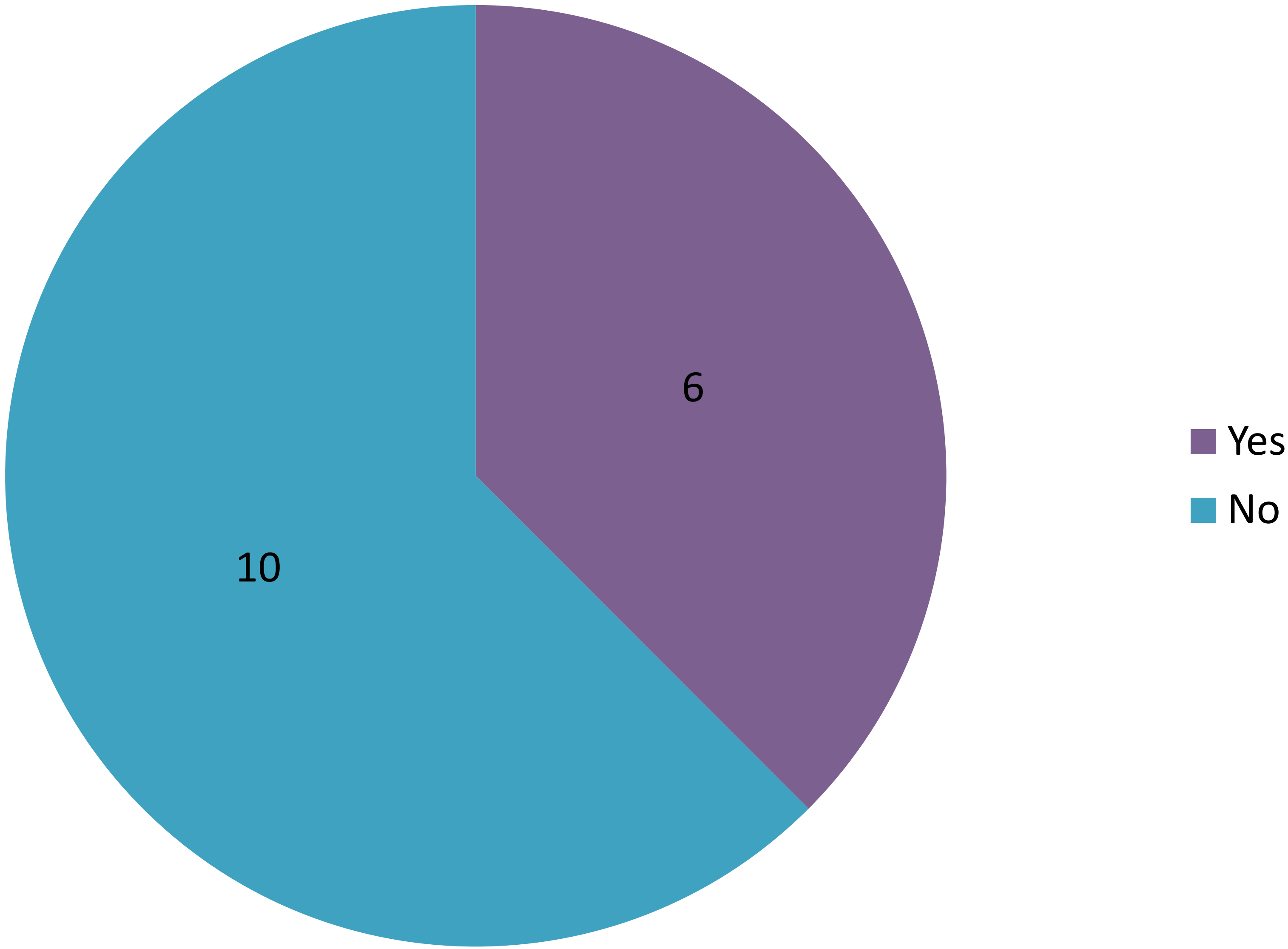




Is your utility required to report to a regulatory authority?



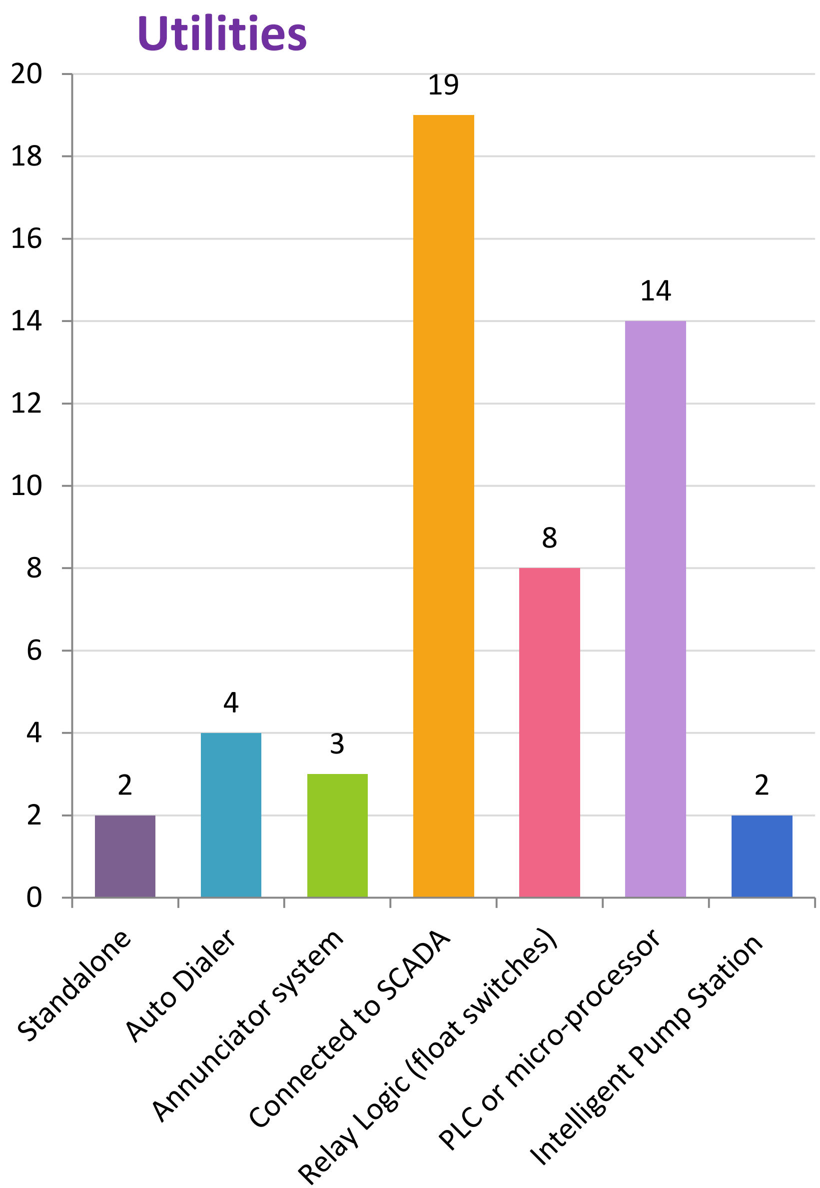
FOR U.S. UTILITIES: Are you currently under a regulatory agreement such as a Consent Decree or Stipulated Order?

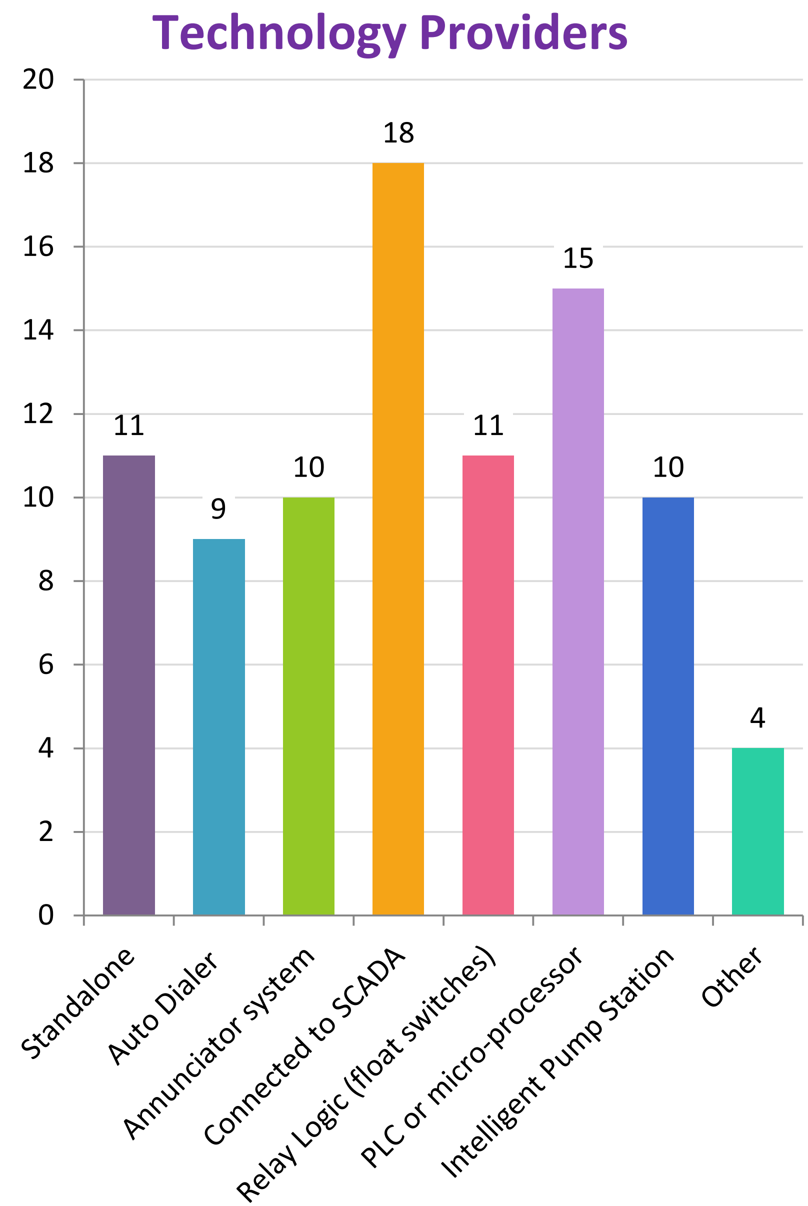


What are your utility's main sewershed network challenges/services? (Adjusted to a 1-3 rating)

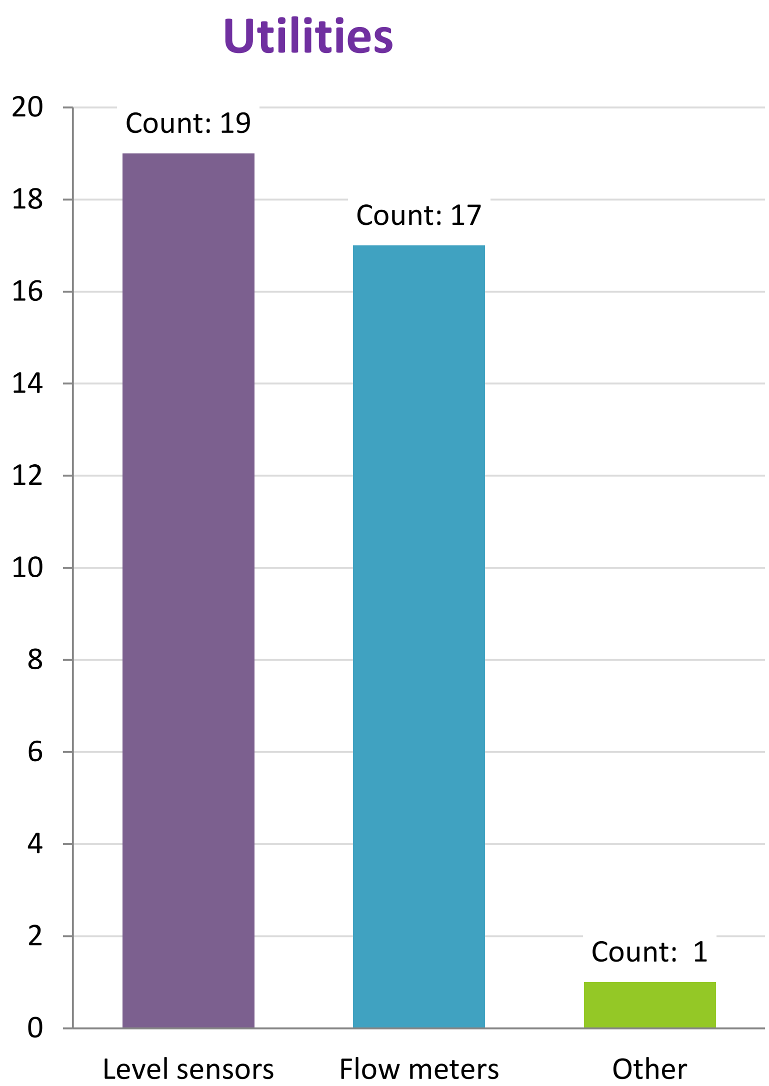
	Utilities			Technology Providers		
	1	**2**	**3**	**1**	**2**	**3**
Compliance monitoring (regulation)	10	4	6	3	3	14
Capacity issues (inflow and infiltration)	3	4	13	1	2	17
Pump (lift) station upgrades/improvements	1	10	9	1	9	10
Inter-agency conflict/communication	8	5	7	6	8	6
Combined Sewage Overflows (CSO's)	13	2	5	2	3	15
Sanitary Sewage Overflows (SSO's)	9	7	4	2	4	14
External flooding and pollution	7	7	6	0	8	12
Customer flooding	9	4	7	4	10	6
Asset management	1	10	9	1	5	14

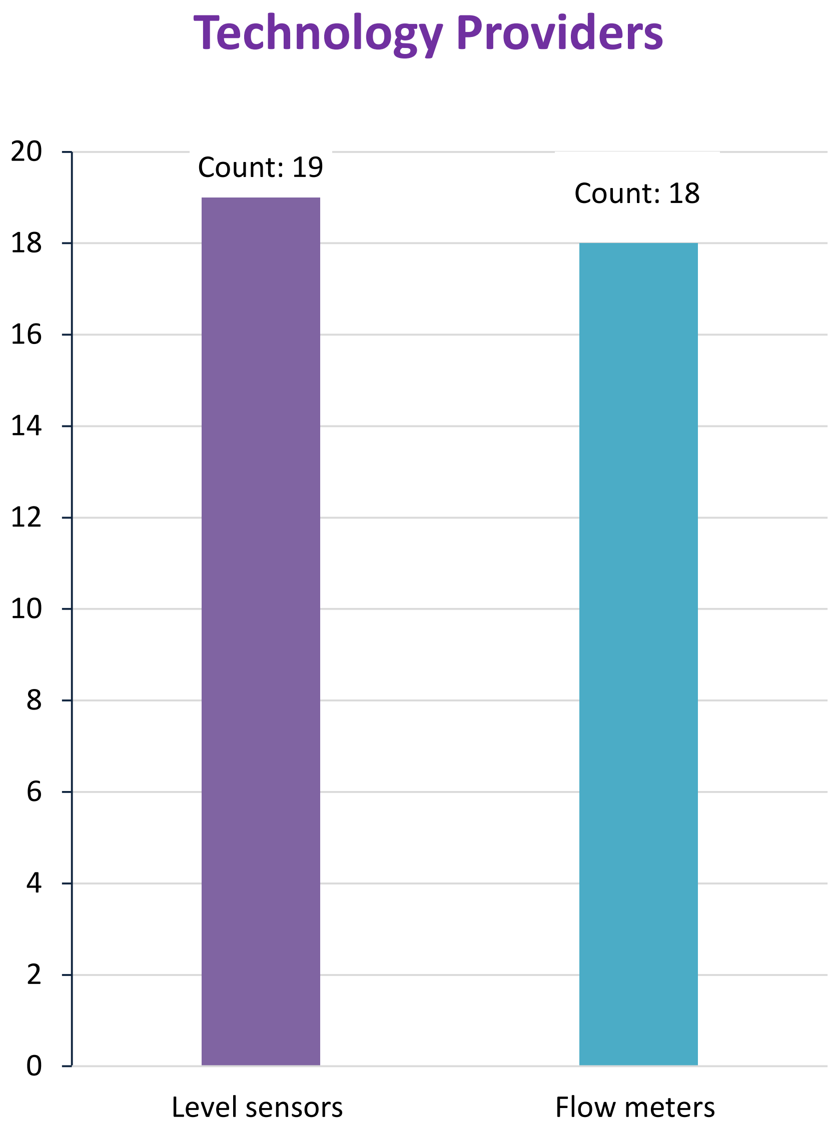
Does your utility use a pump station control system, if so, to what type? Please select all that apply.



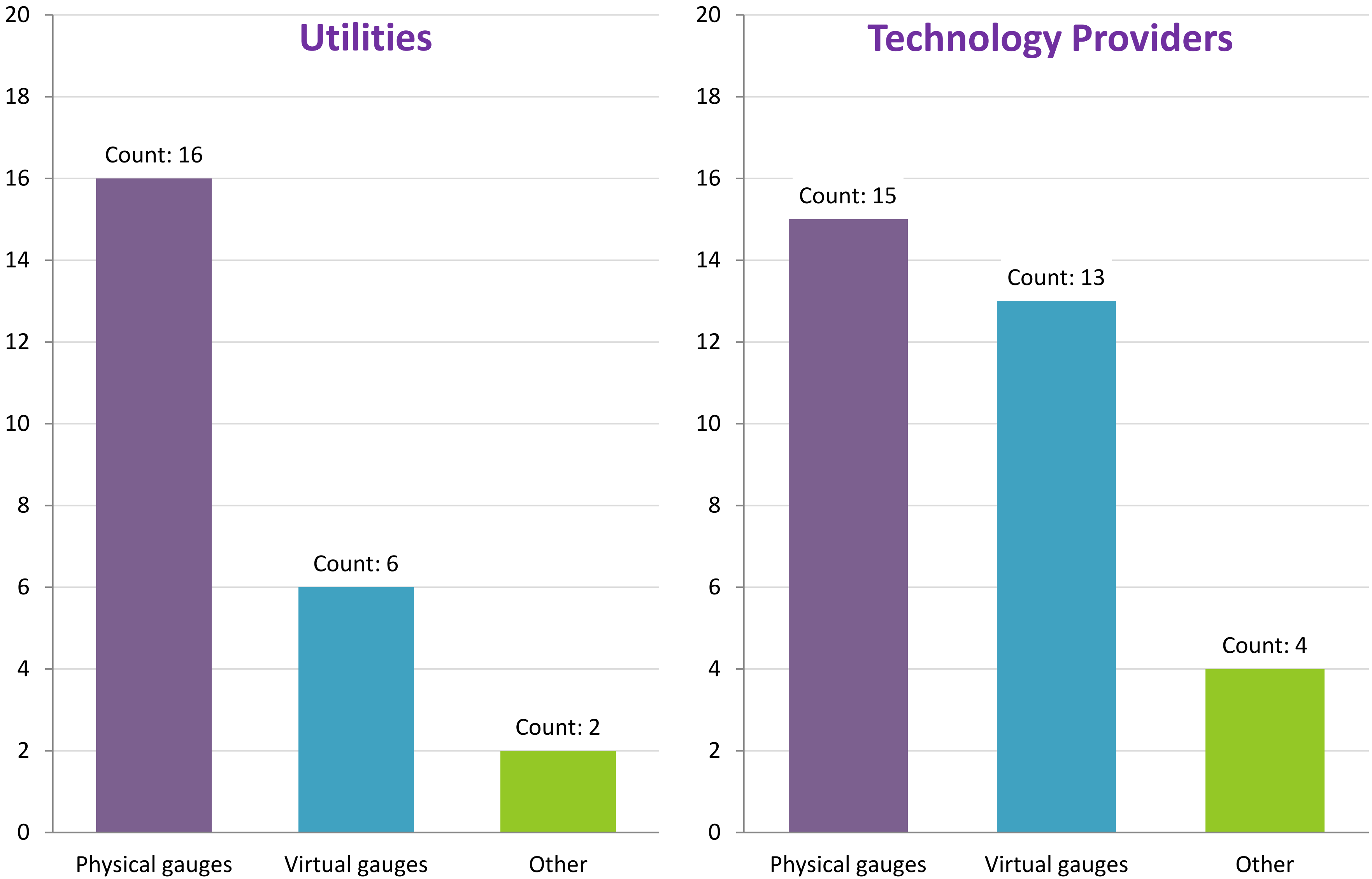


Which online sensors does your utility use to measure water levels or flow in the sewershed network(s)?

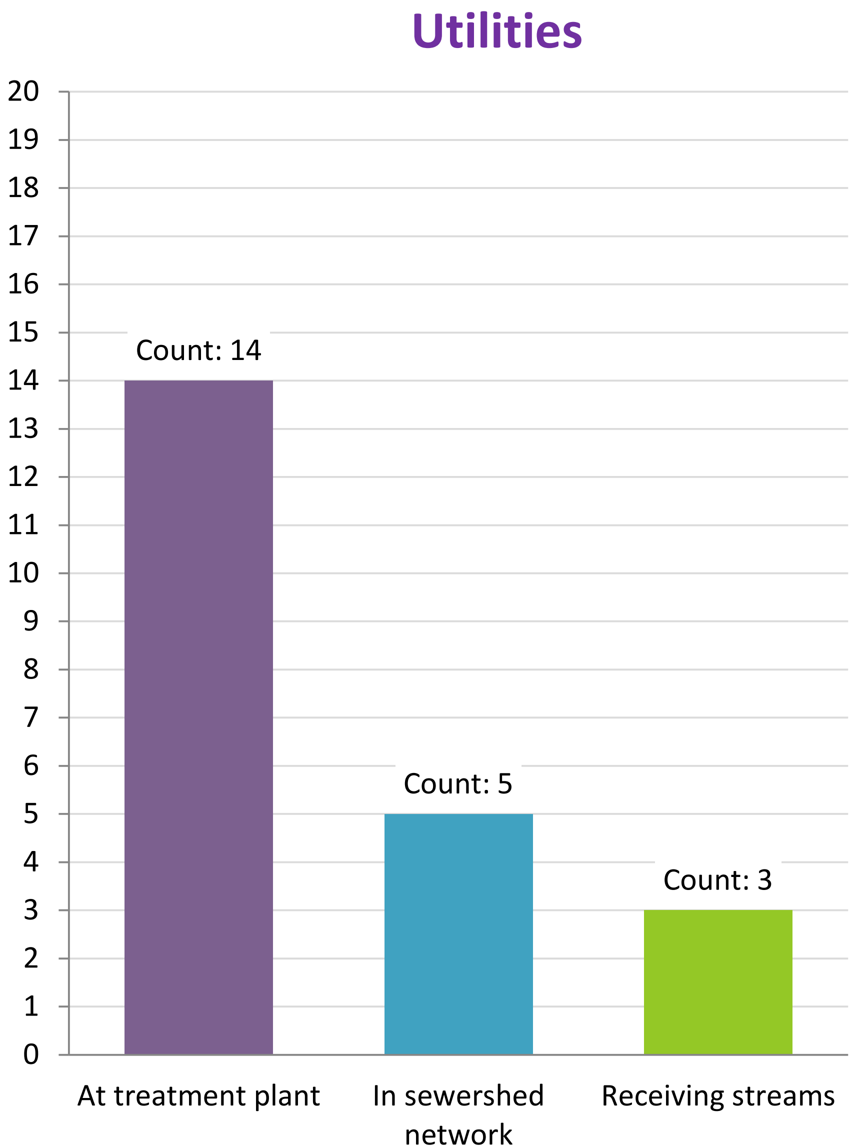


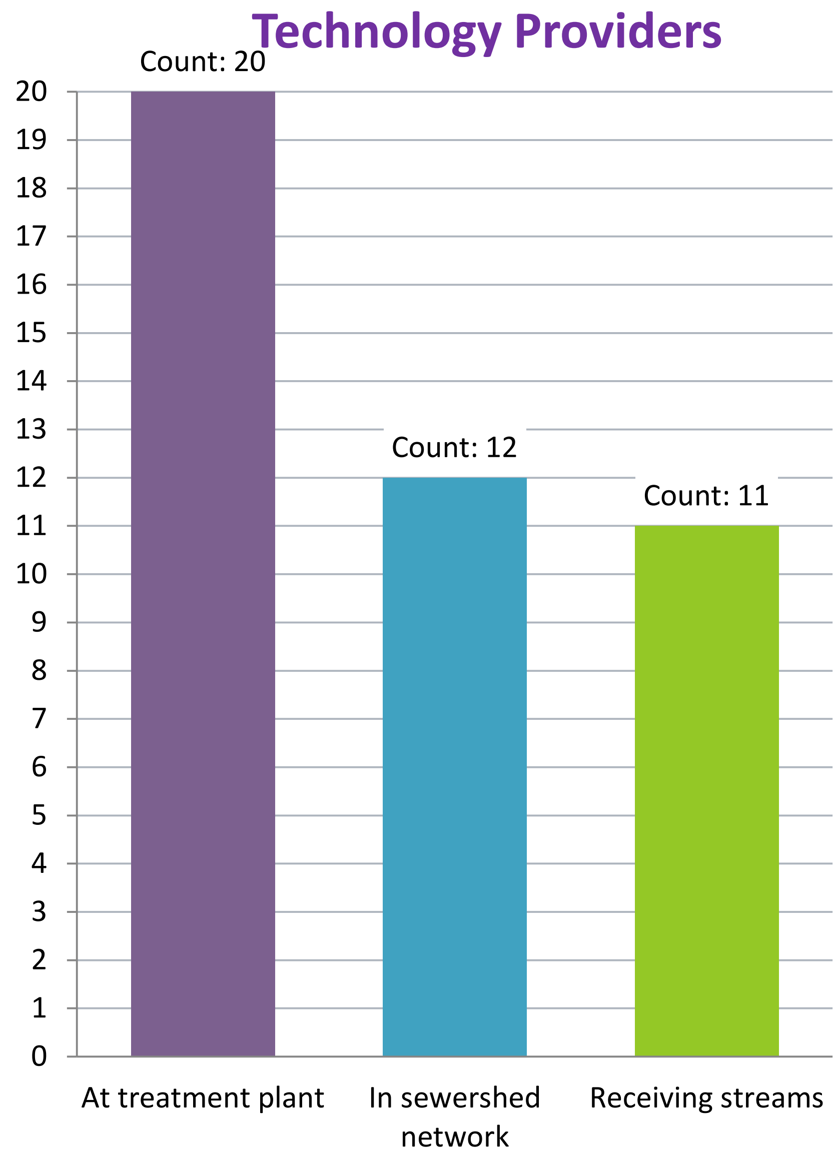


Which rain gauge sensors does your utility use to measure and transmit data about current sewershed weather conditions?

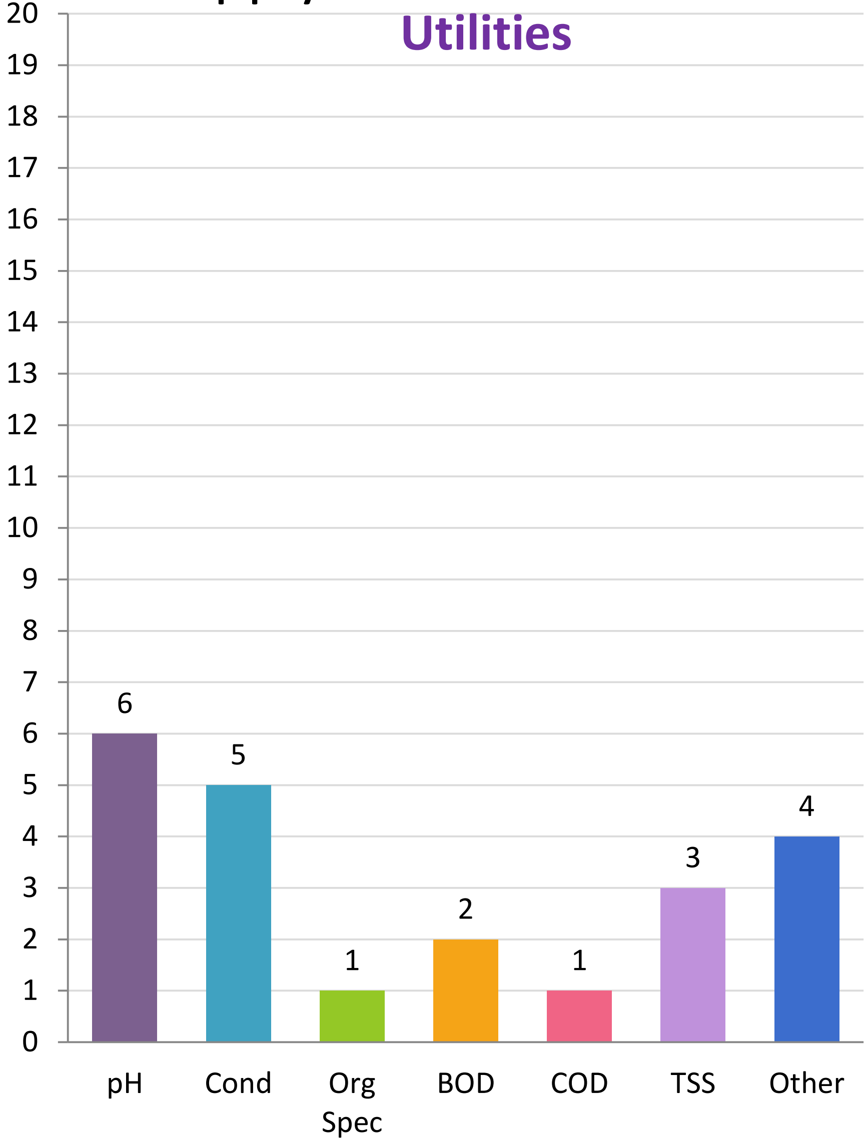


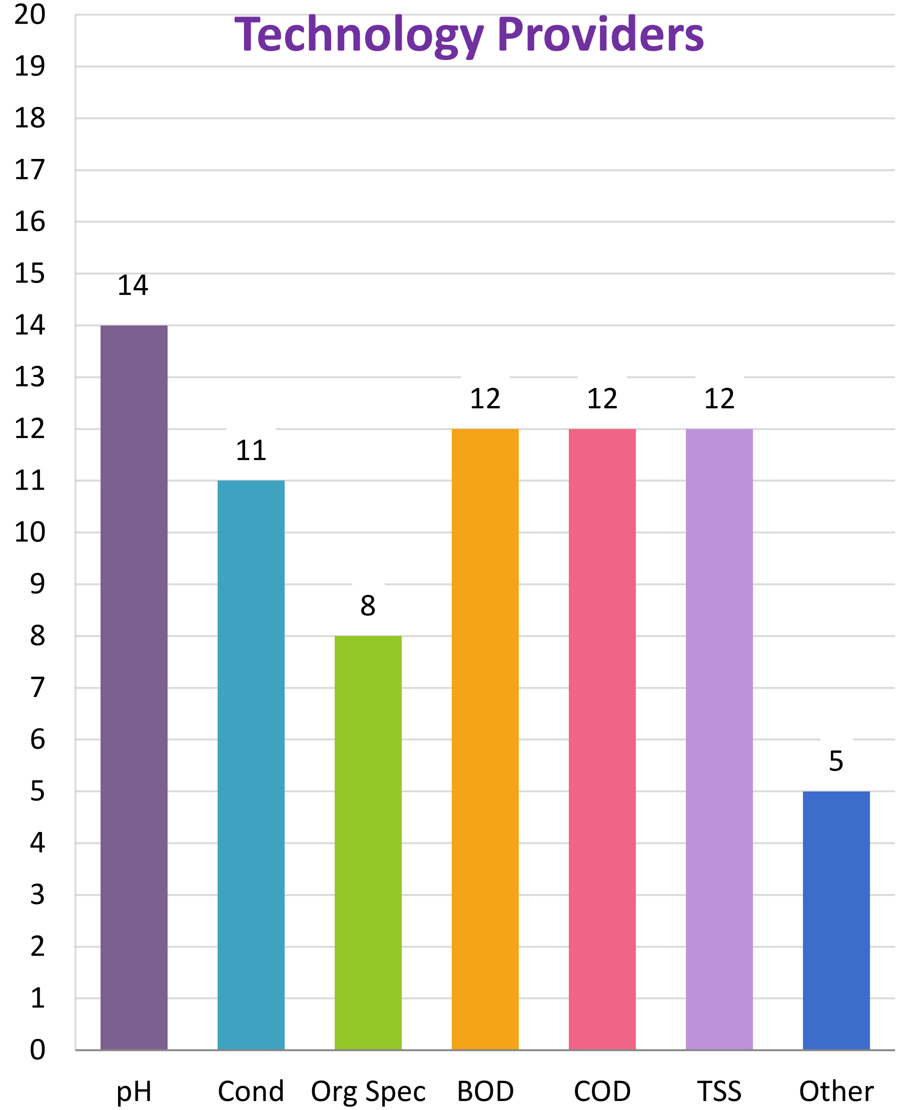
Does your utility use online sensors to measure water quality in the sewershed network(s)? Please select all that apply.



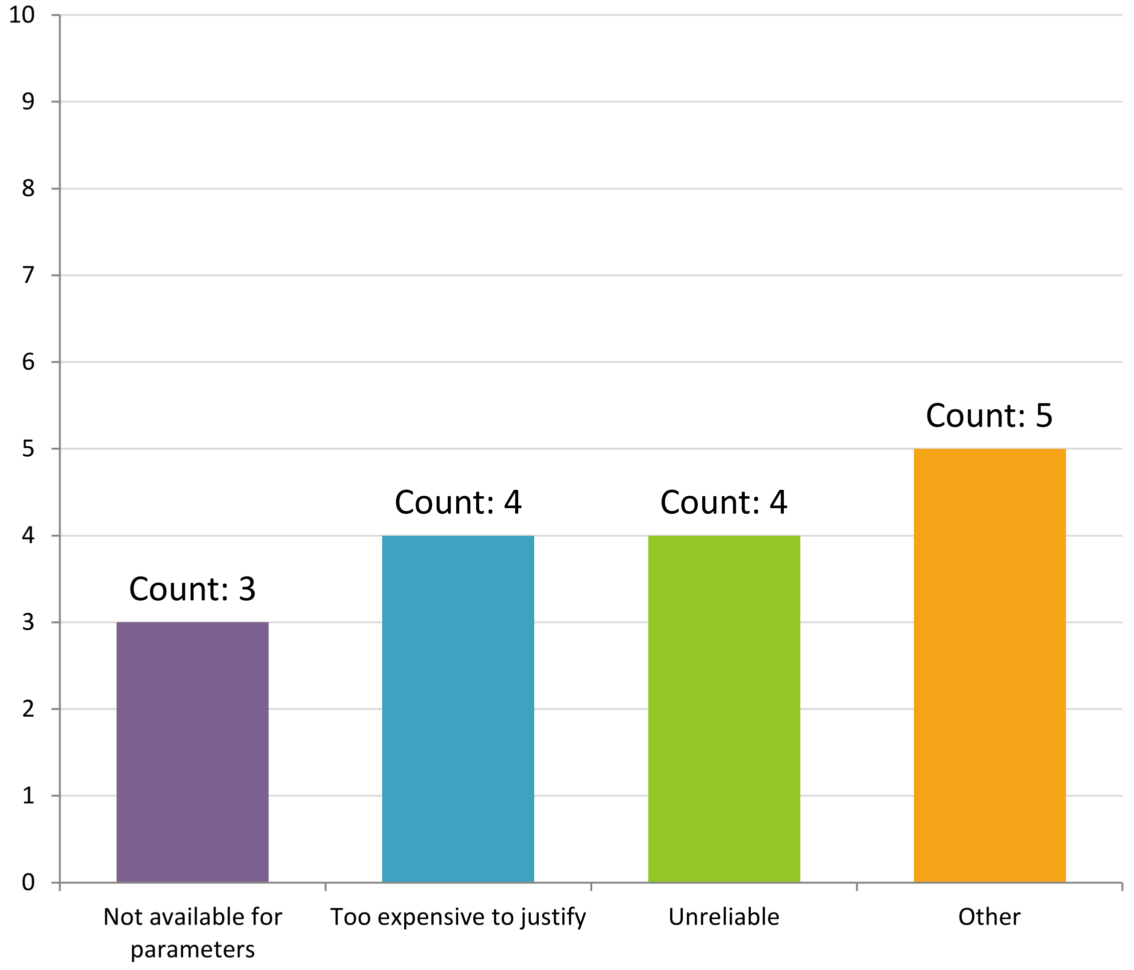


If your utility does use online sensors to measure water quality in the sewershed network, which parameters do you measure? Please select all that apply.





For the parameters that you would like to measure, but currently can’t, why can’t you measure them? Please select all that apply.



Total Respondents: 12

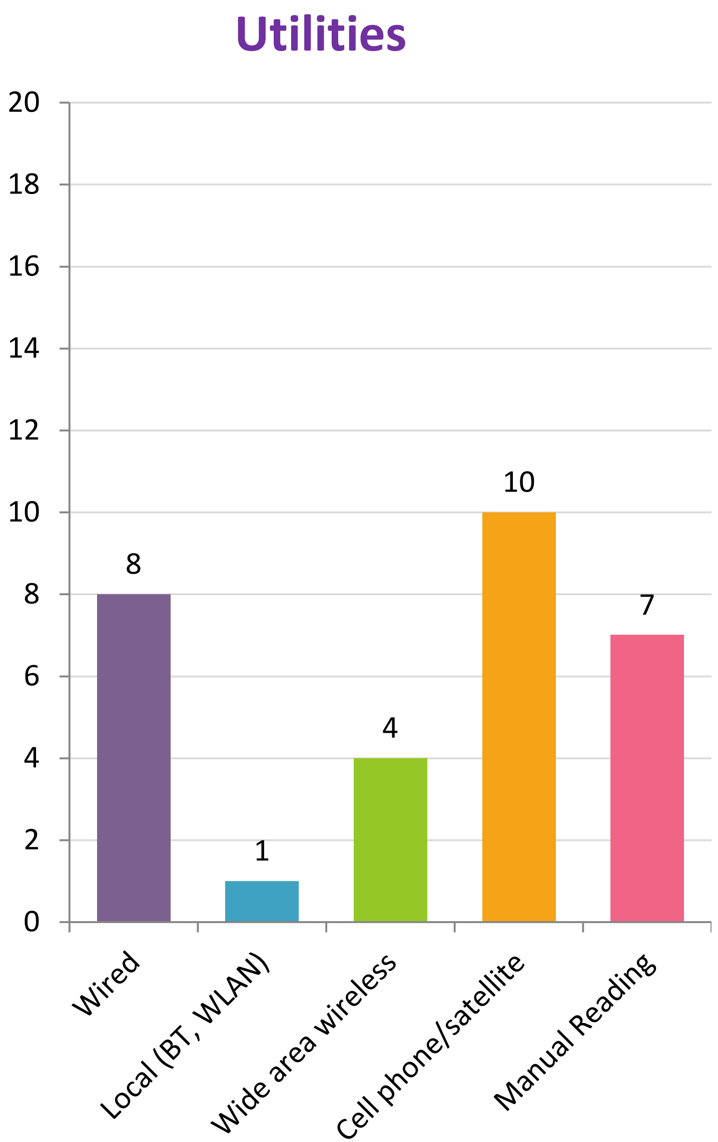
If your utility does not use any type of online sensors, what barriers do you see for implementing them? (Adjusted to a 1-3 rating)

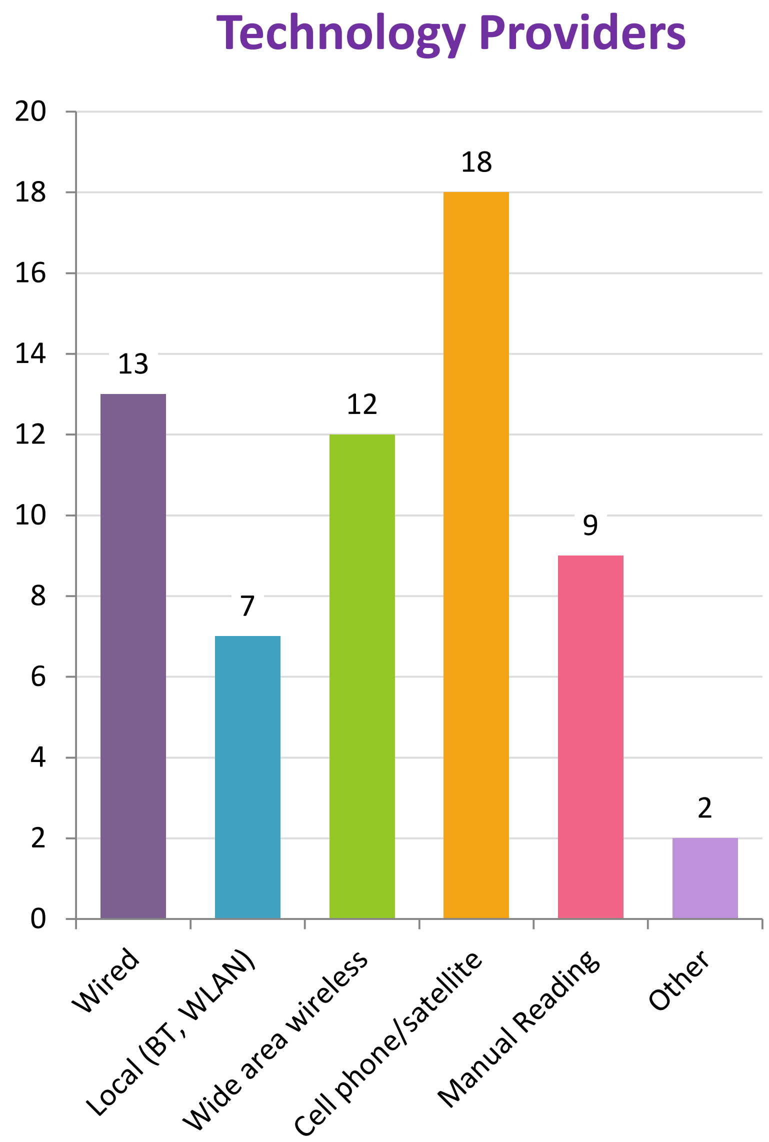
	Utilities			Technology Providers		
	1	**2**	**3**	**1**	**2**	**3**
Unreliable data (False alarms)	5	3	4	9	6	3
Too expensive (acquisition)	4	4	5	3	3	11
Too expensive (O&M)	2	4	7	3	4	11
Lack of skilled personnel	5	6	2	4	8	6
Organizational barriers	8	3	2	5	5	8
Lack of a business case	4	2	7	7	6	5
Lack of suitable technology				9	2	6

If your utility does use any type of online sensors, what were the main driving forces (rationale) for adopting them? (Adjusted to a 1-3 rating)

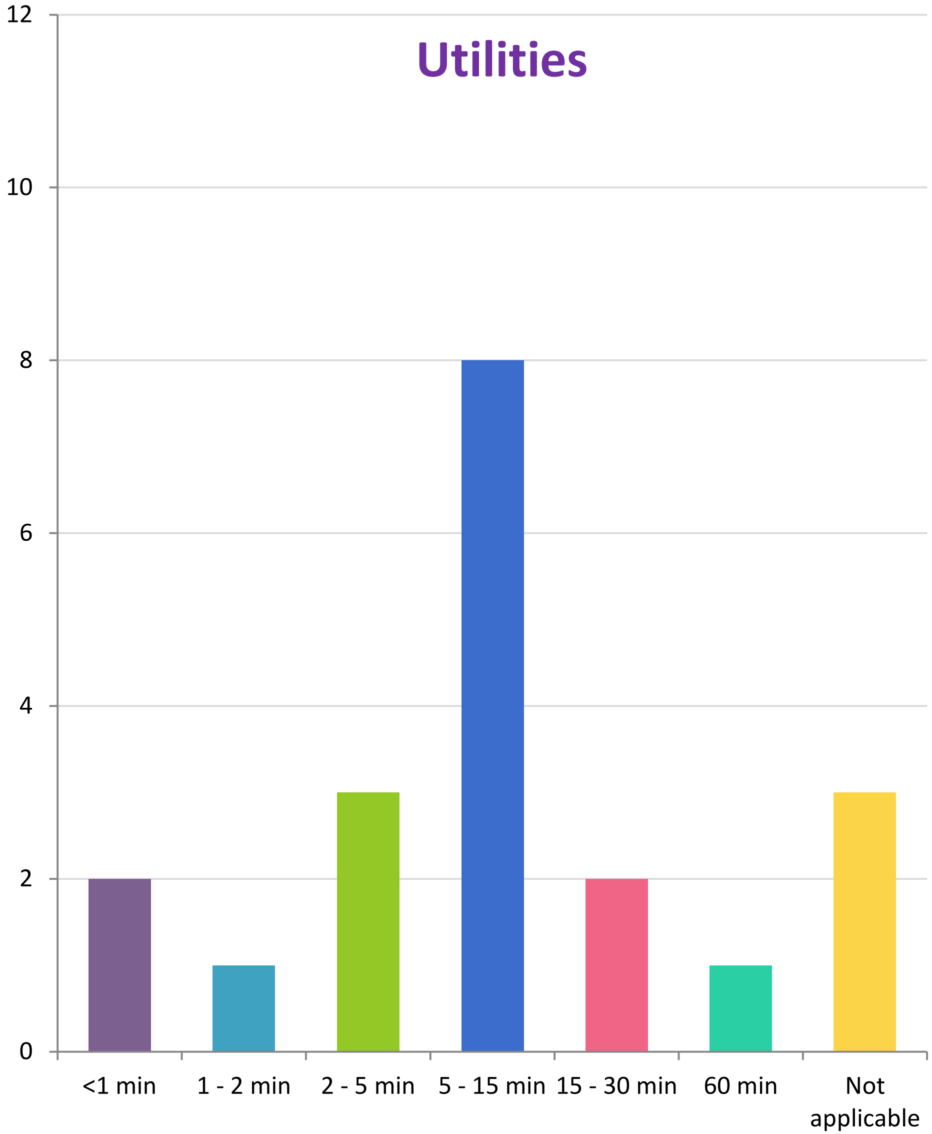
	Utilities			Technology Providers		
	1	**2**	**3**	**1**	**2**	**3**
Research	5	6	3	12	3	3
Real-time Control	3	3	8	2	3	13
Regulation/Compliance Monitoring	2	2	9	1	3	14
Early Warning System (sewershed or influent)	0	4	10	0	3	16

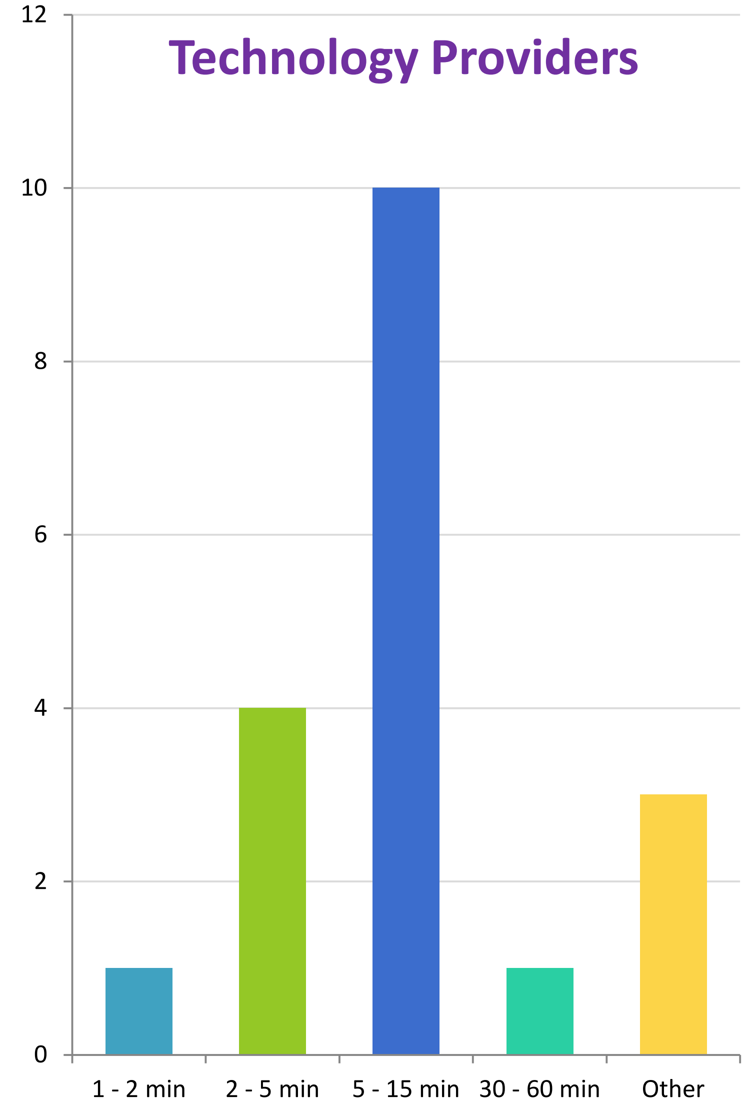
If your utility does use online sensors, what type of communications system do you use predominantly? Please select all that apply.



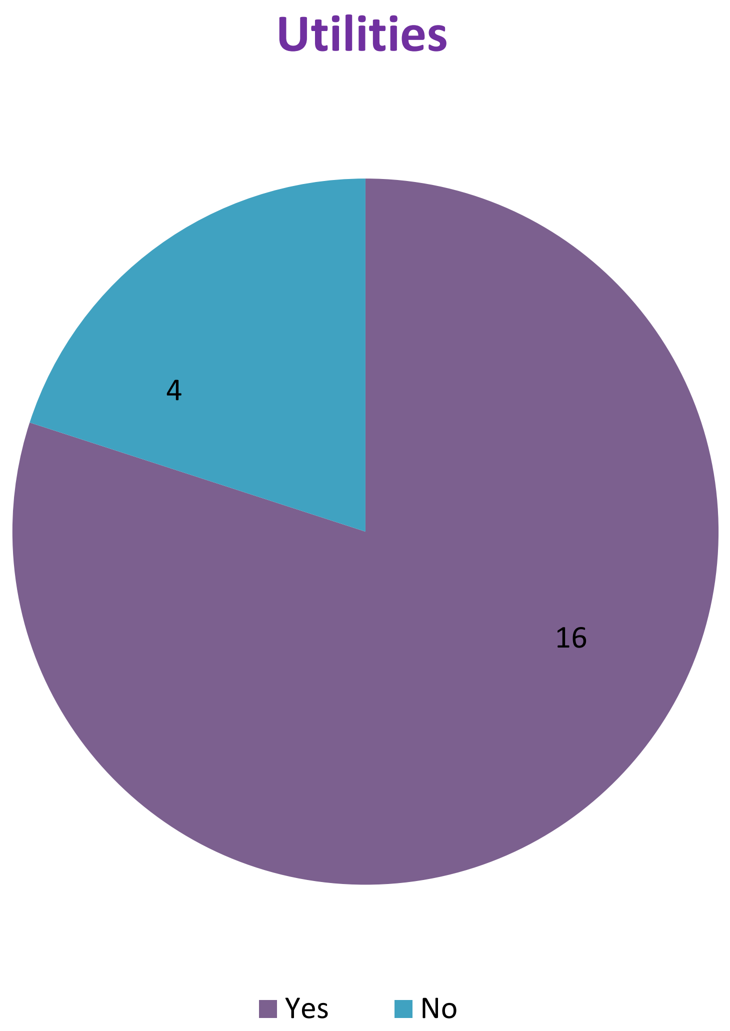


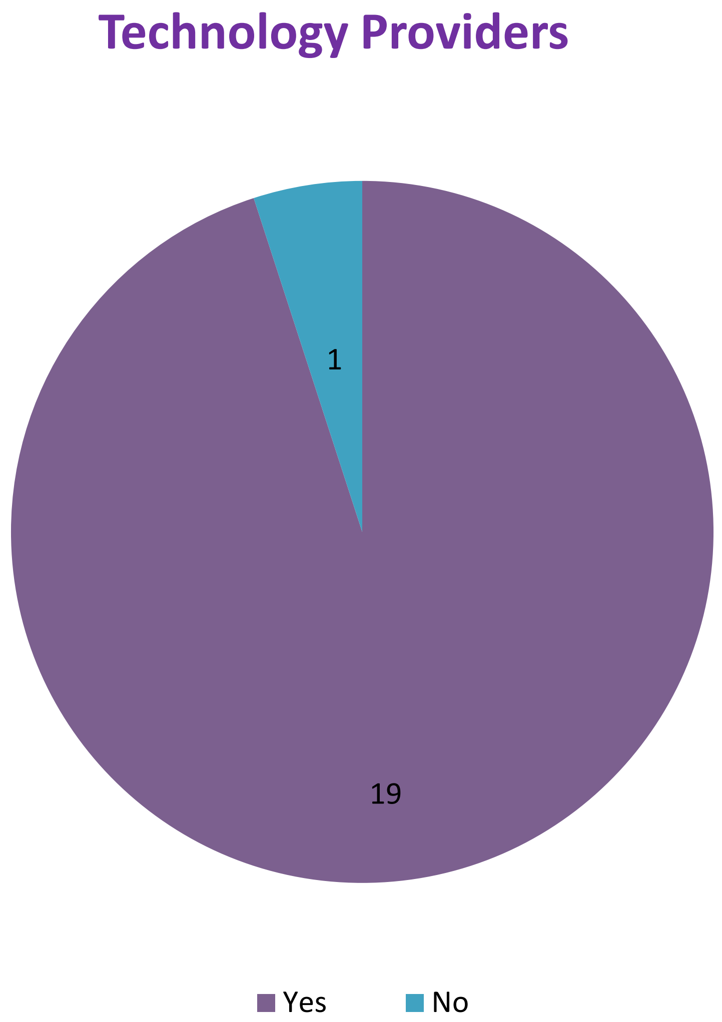
What is your utility's average measurement frequency from online sensors in the sewershed network(s)?



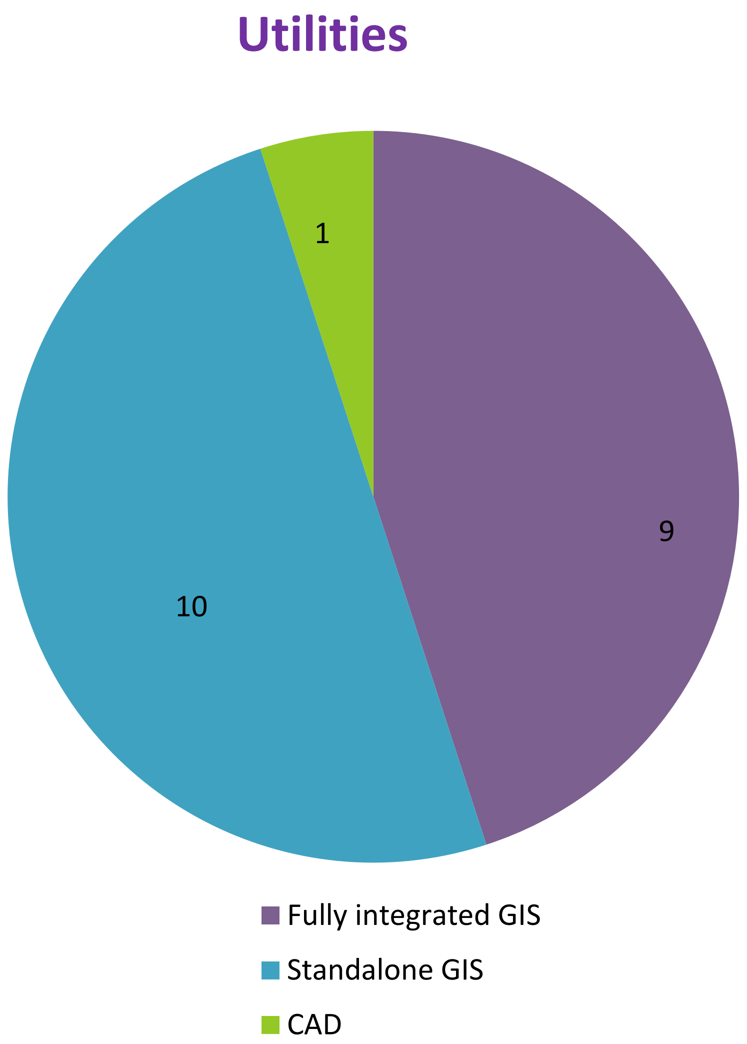


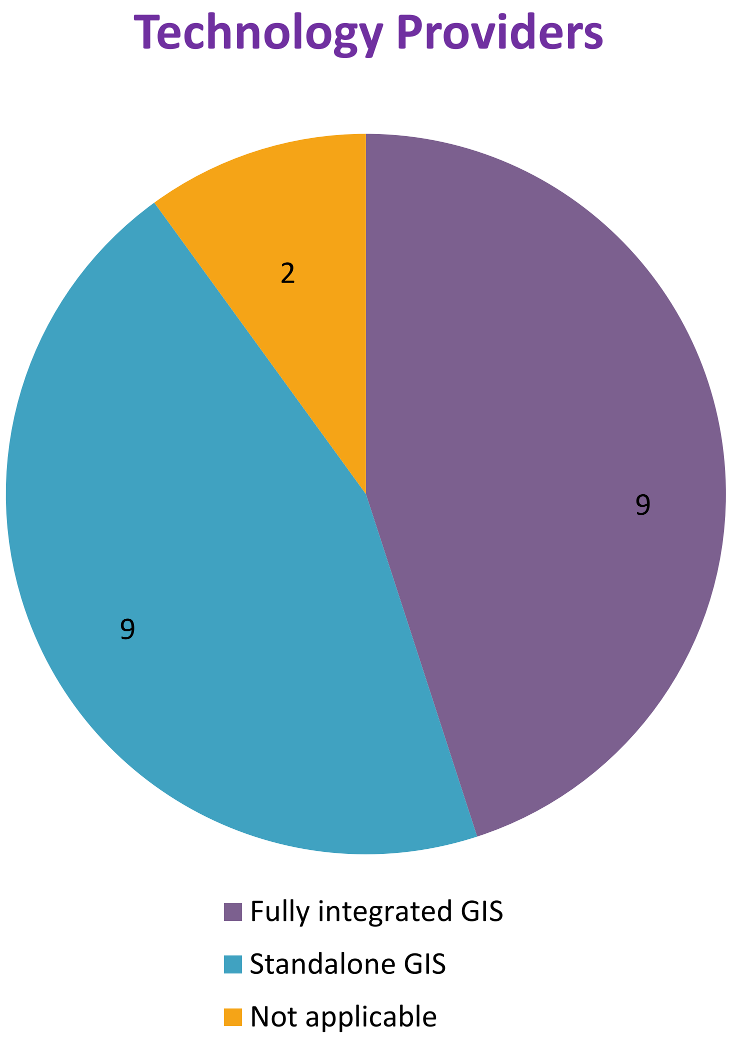
Does your utility have a supervisory, control and data acquisition system (SCADA) installed and monitoring a sewershed network?



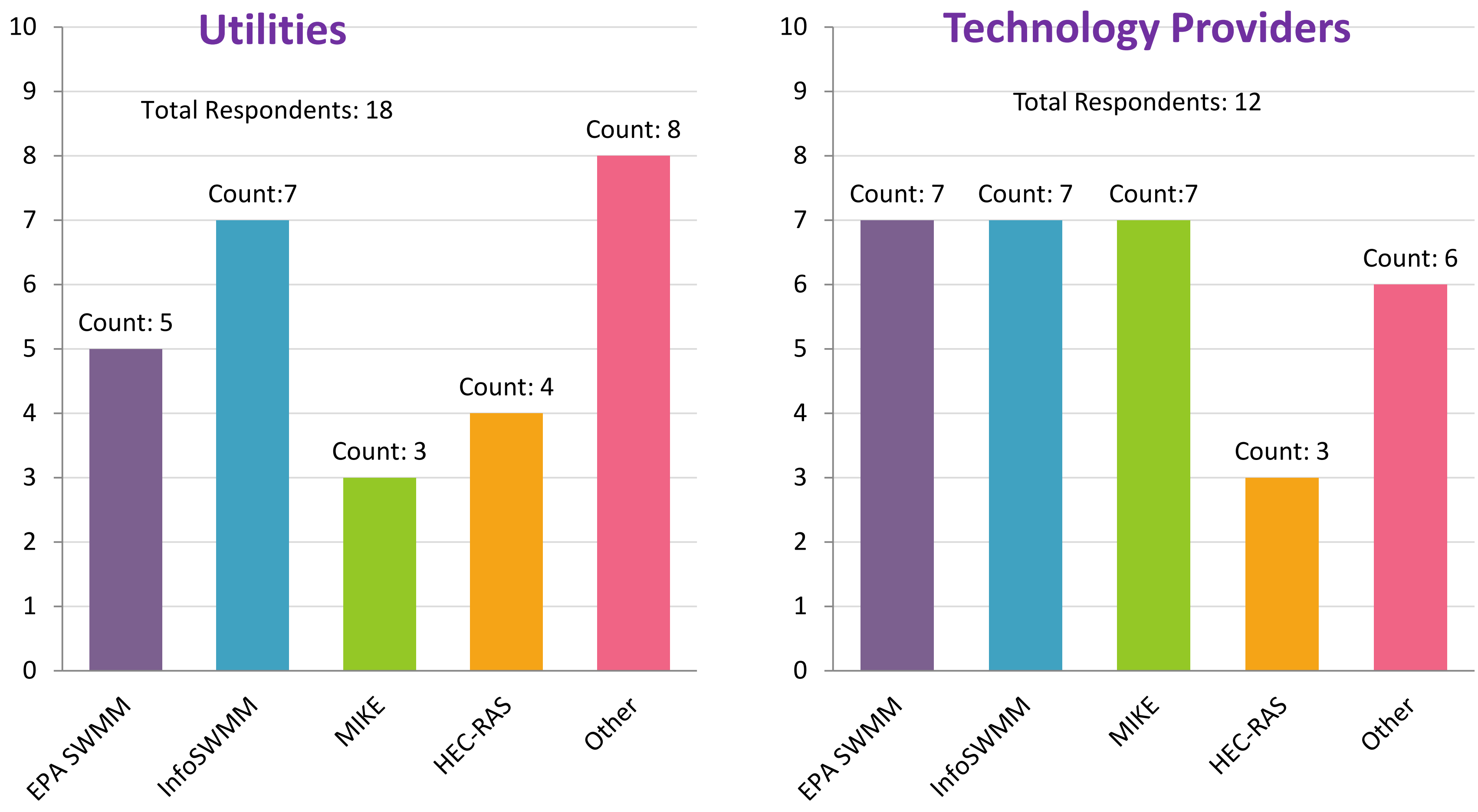


Does your utility currently have sewer system assets mapped in a Geographic Information System (GIS)? If so, what type?



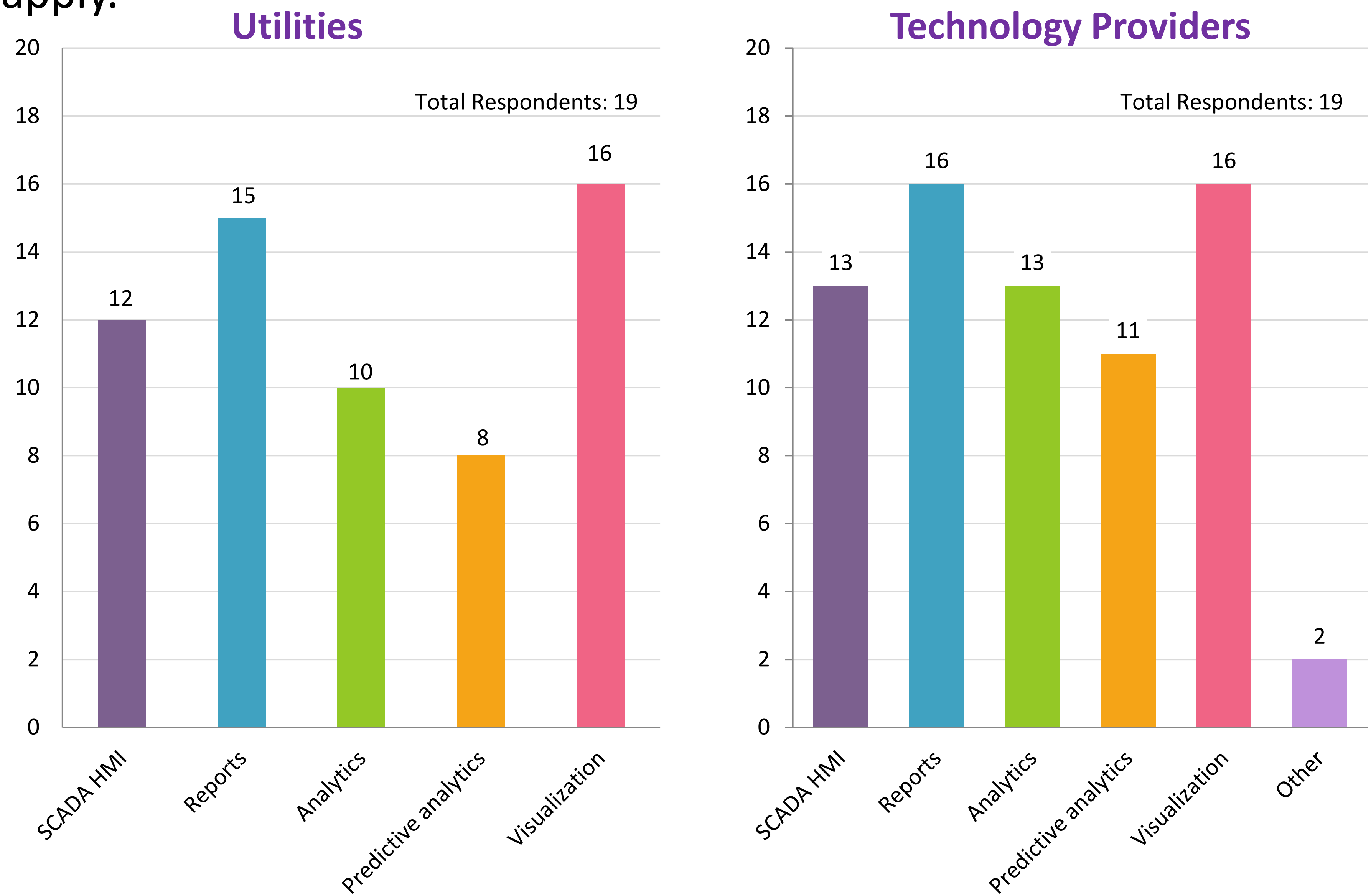


What types of hydraulic modeling software does your utility use? Please select all that apply.

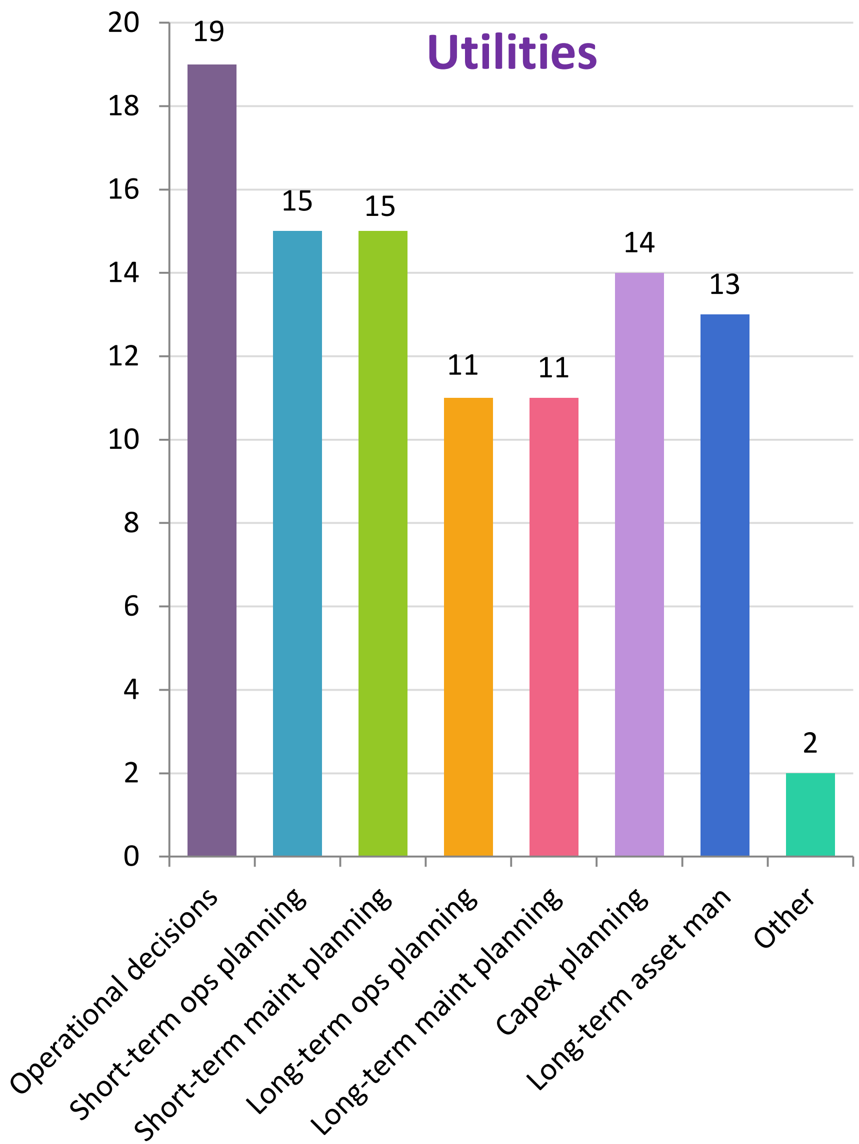


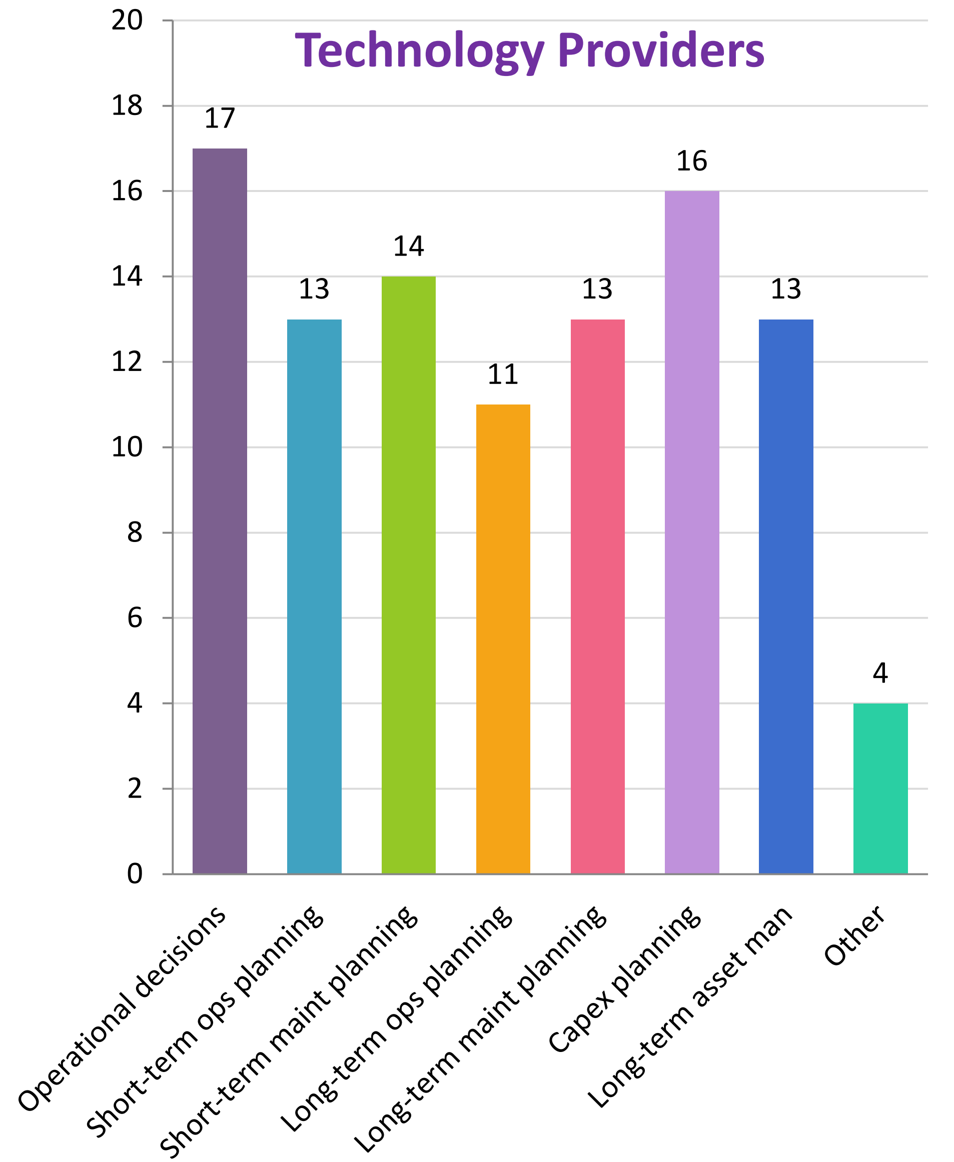
Other includes: InfoWorks ICM, CalSim, KOSIM, SewerCAD, WaterCAD, XPSWMM, SWMMLIVE, HSPF

Does your utility use any of the following to analyze information from the different sewershed network data streams? Please select all that apply.

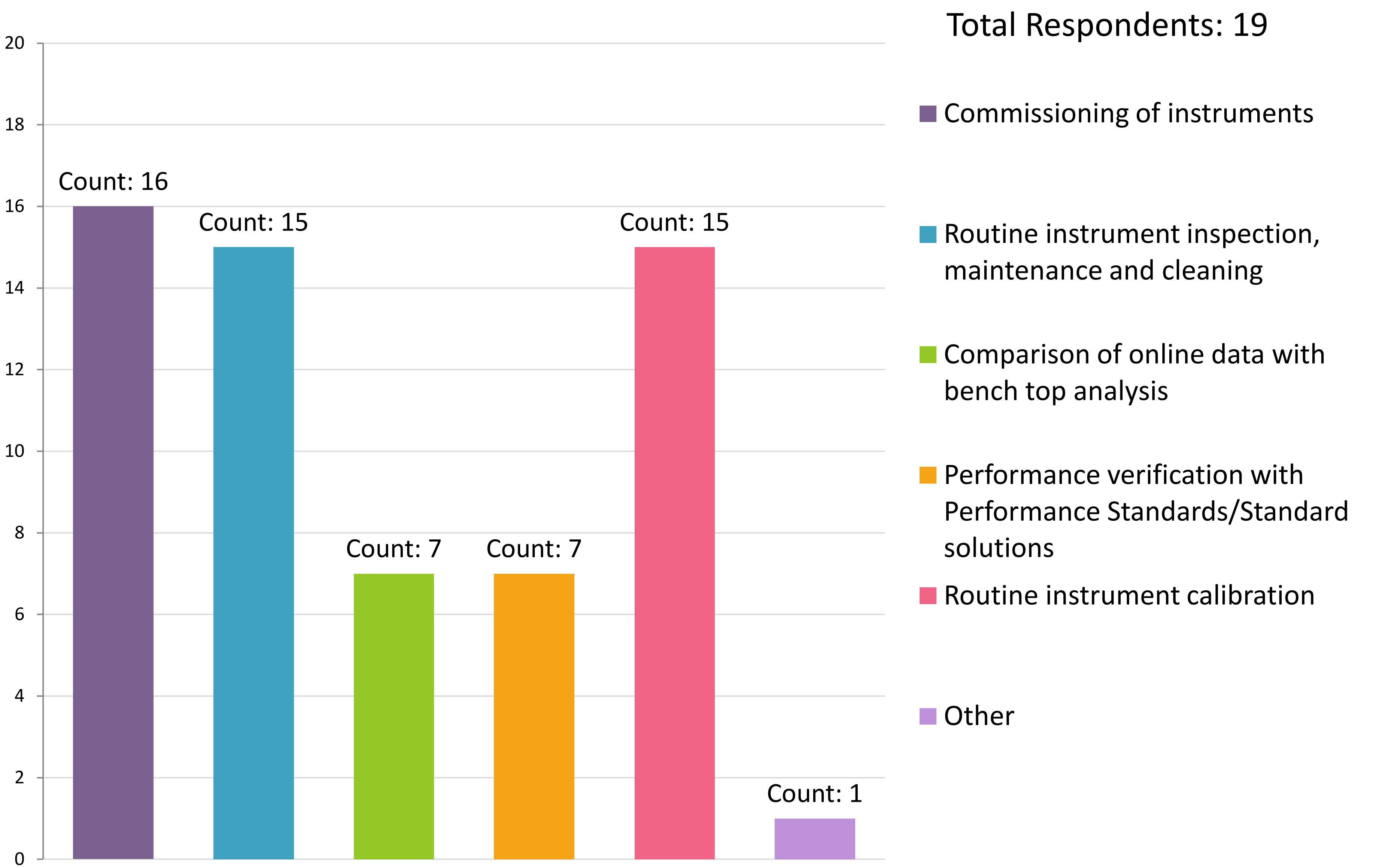


What does the information get used for? Please select all that apply.

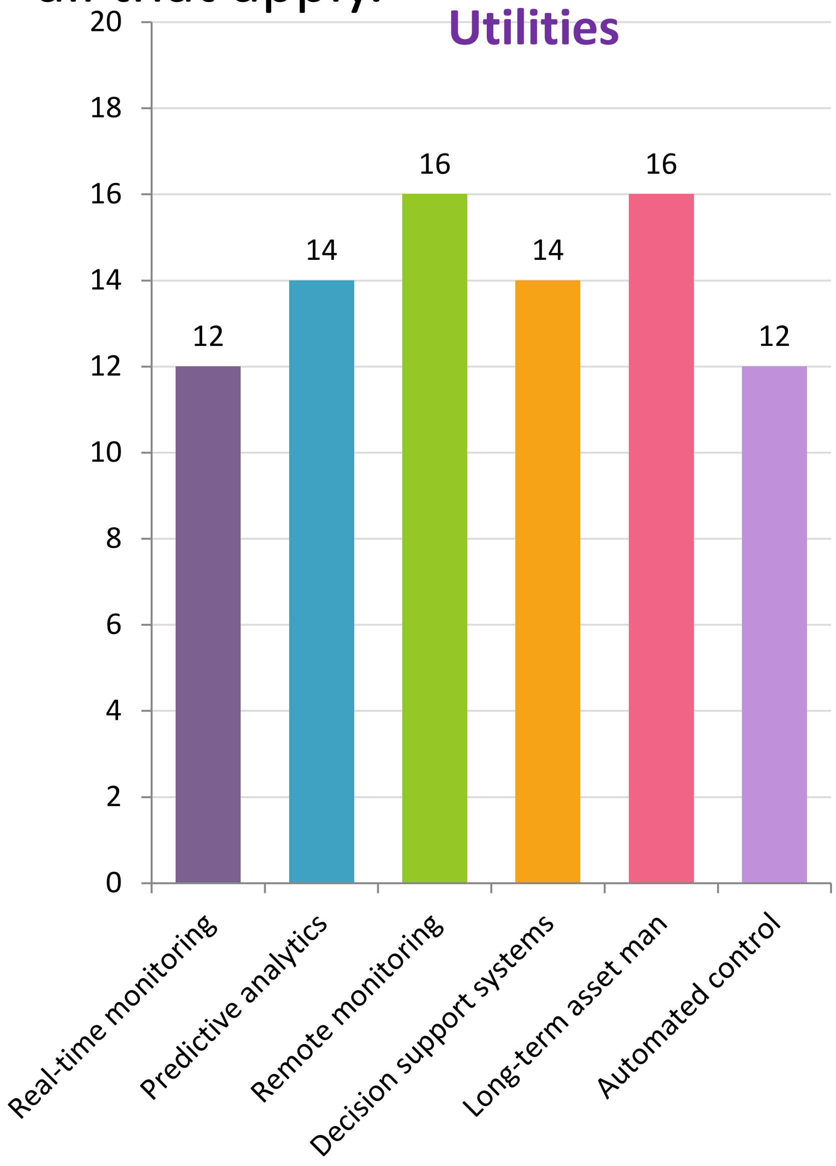


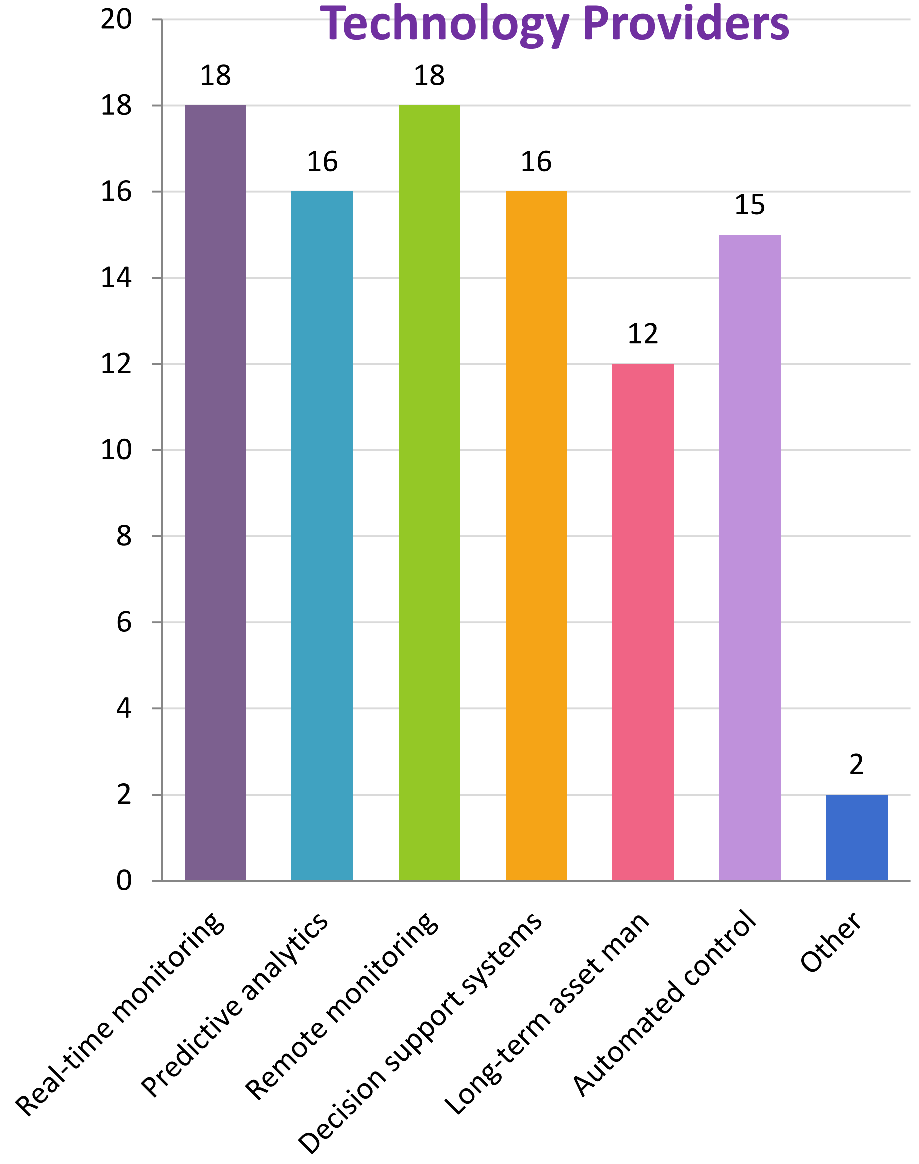


Which of the following activities are part of your utility's QA/QC program? Please select all that apply.

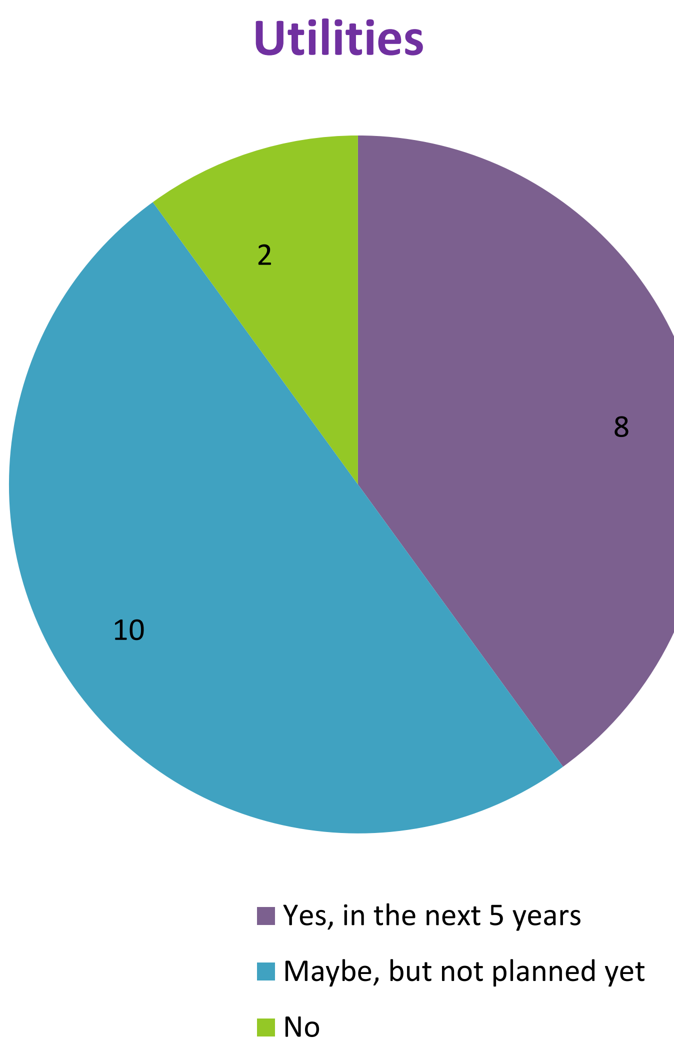


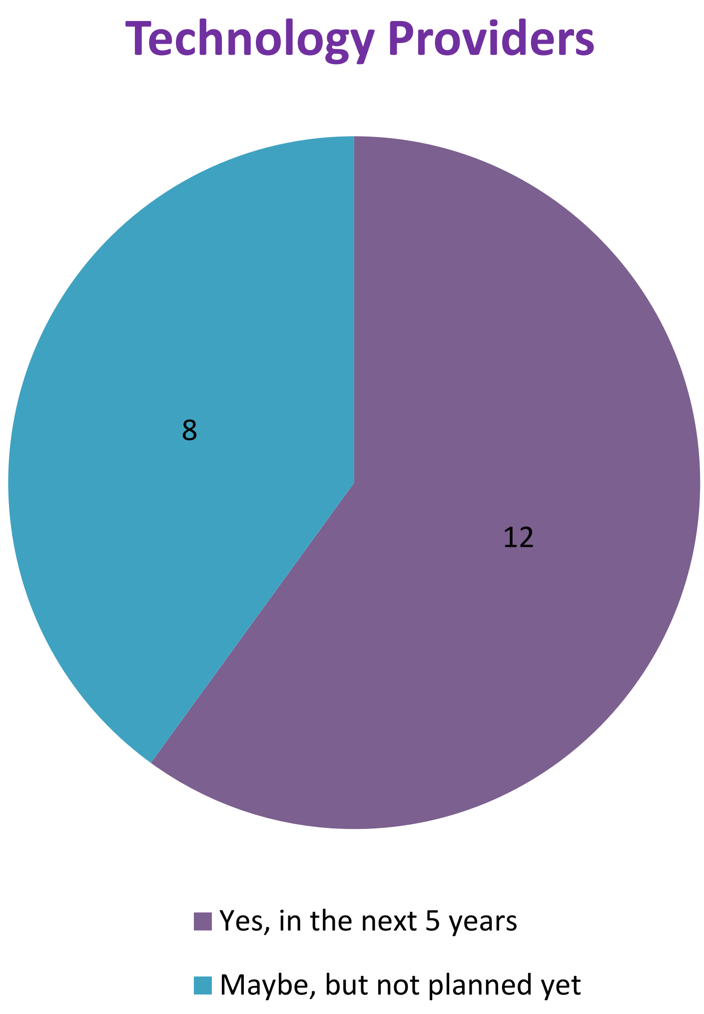
Does your utility have interest in using any of the following advanced, online sewershed network technologies or processes? Please select all that apply.



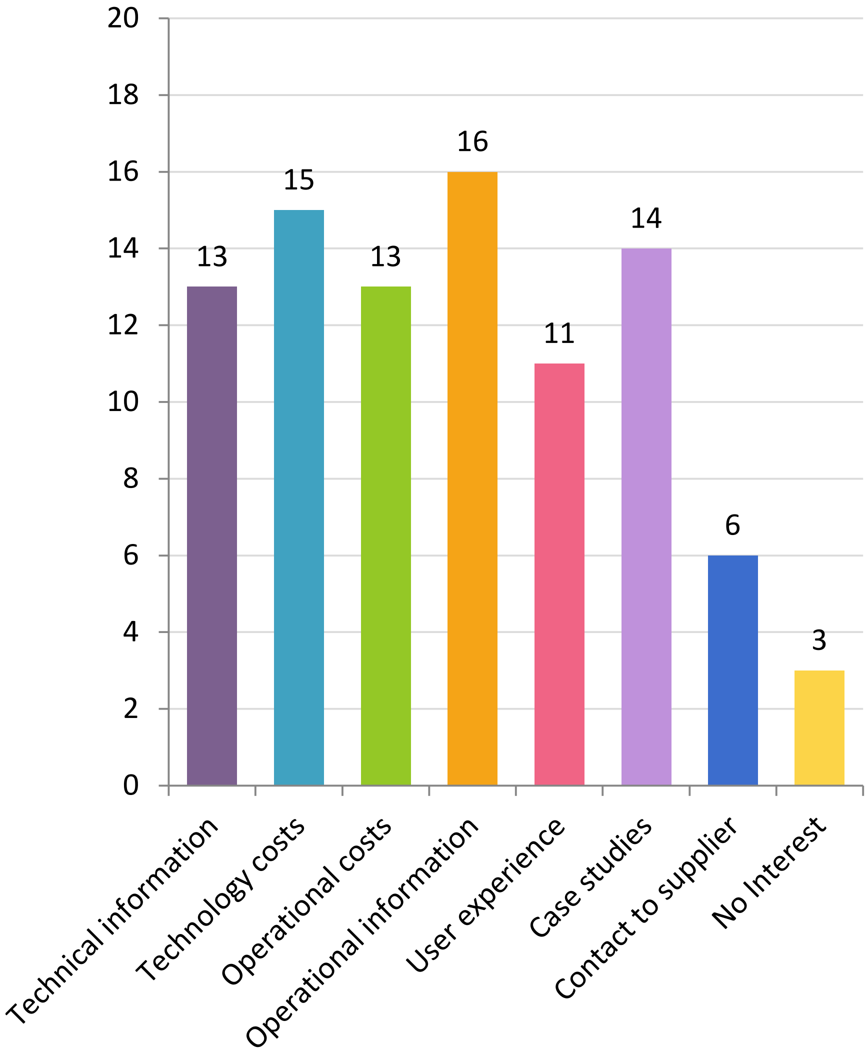


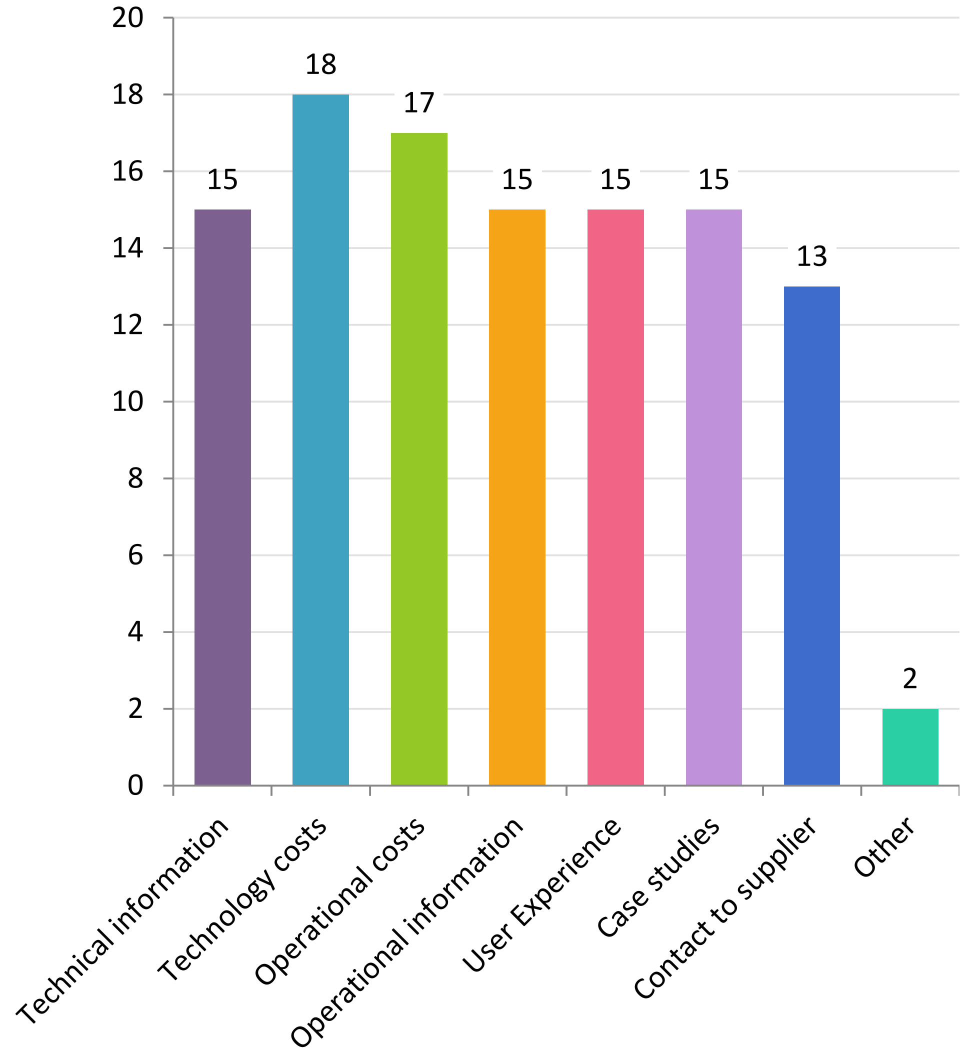
Does your utility intend to significantly increase your investments in advanced, online sewershed network management, as part of your long-term strategy?



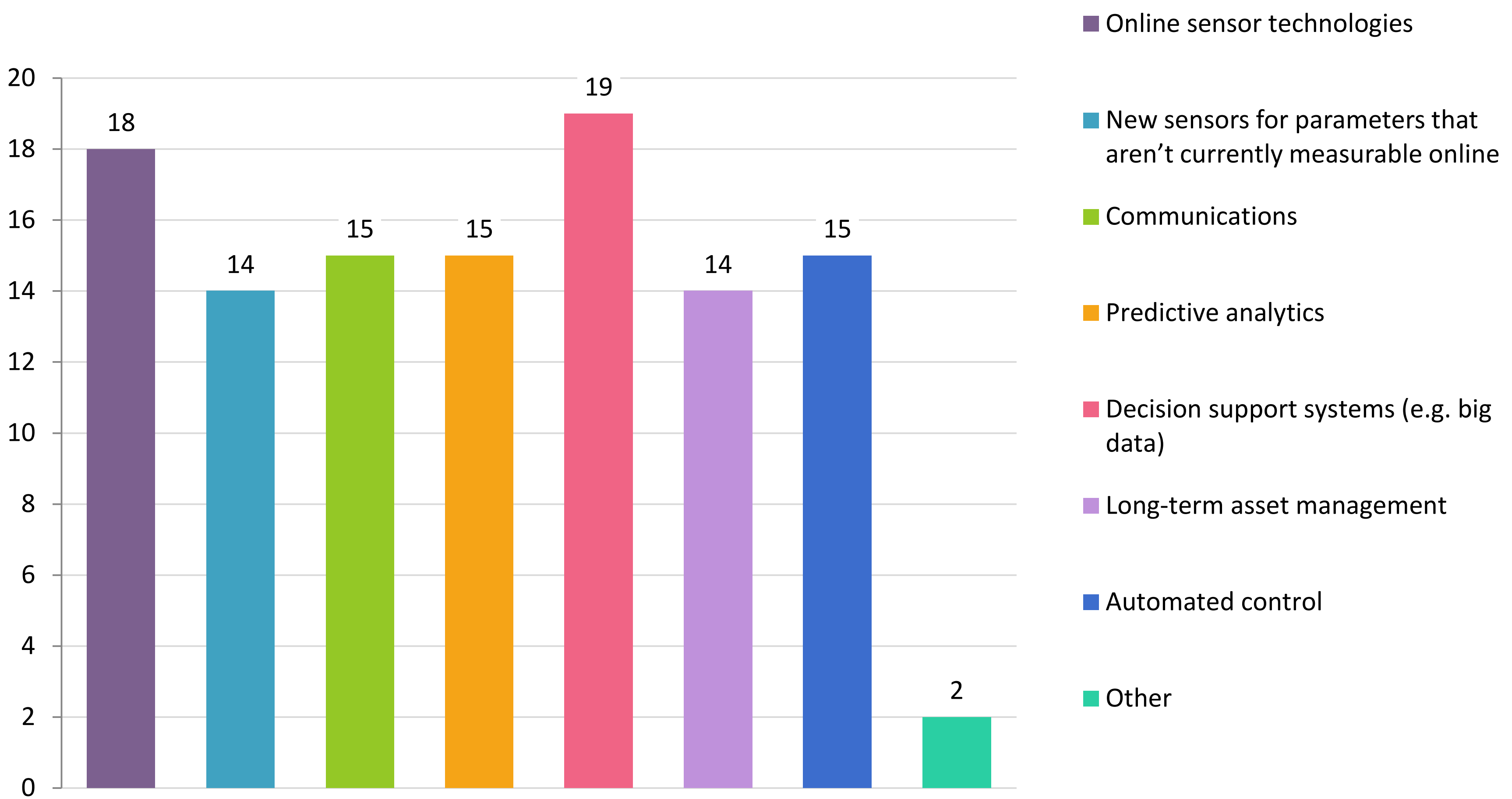


What type of information would your utility be looking for regarding advanced, online sewershed network management? Please select all that apply.



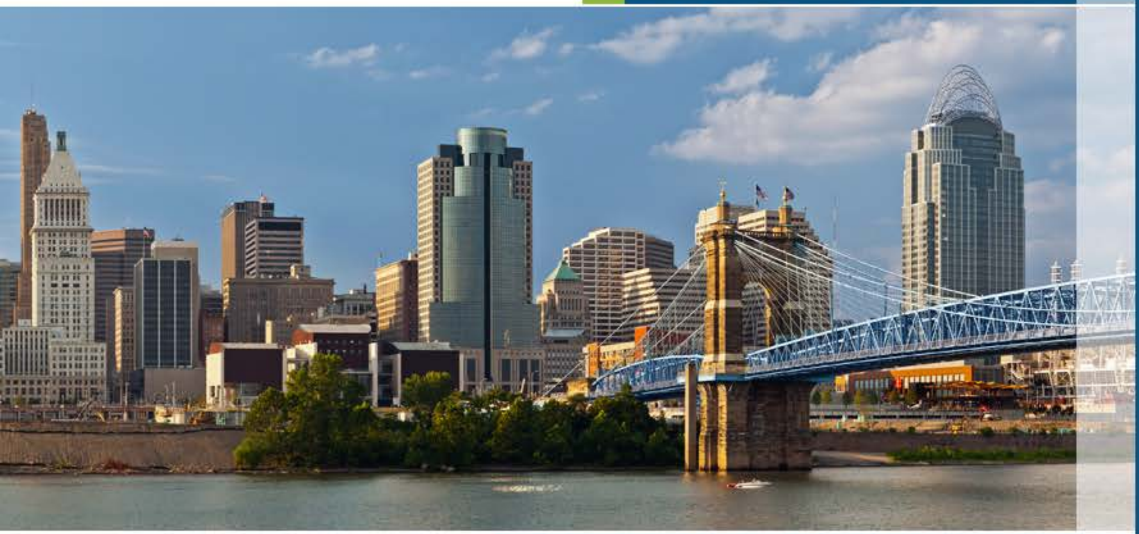


As a supplier of technologies to water and wastewater utilities, where do you expect new products with new capabilities will be available in the next 5 years?



Additional comments about what keeps you up at night:

Count	Response
1	Lack of risk management, lack of real-time information, lack of appropriate instrumentation and monitoring.

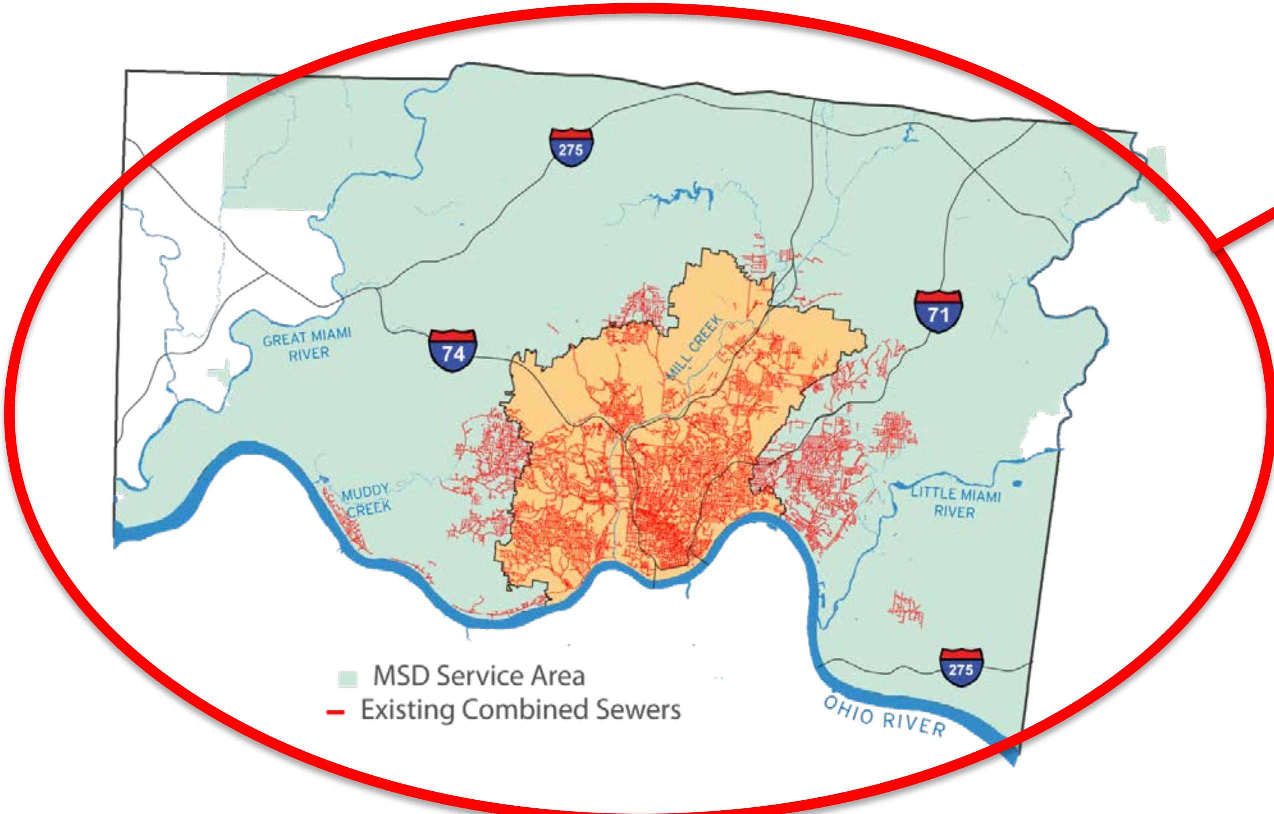


Building a Smart Sewer System to Reduce Wet Weather Overflows

Reese Johnson, PE, PMP

Metropolitan Sewer District of Greater Cincinnati

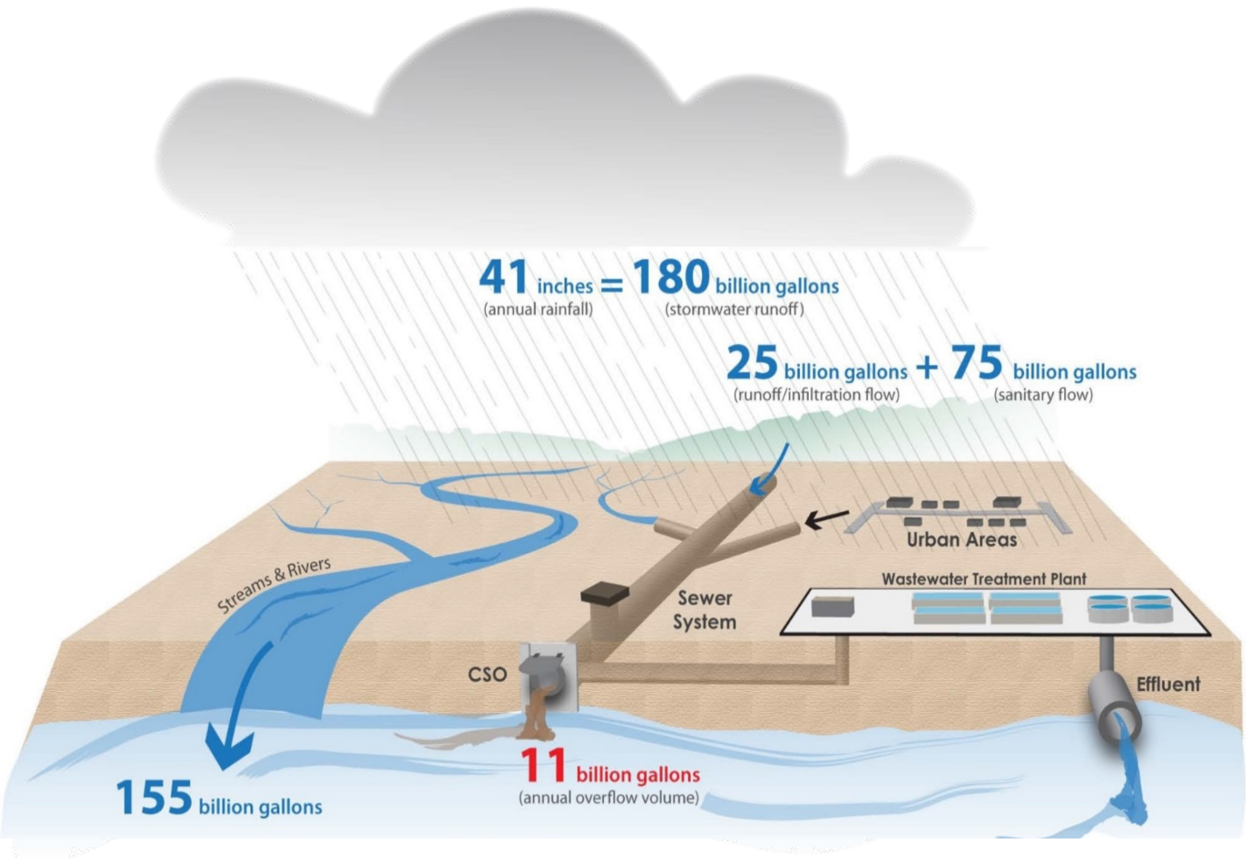
MSD of Greater Cincinnati, Ohio



- 800,000+ Residents of Cincinnati and Hamilton County
- 290 Square Miles
- 7 Treatment Plants
- 100 Pump Stations
- 7 Wet Weax Facilities
- 3,000 Miles of Sewers
- Treats 184 MG per day

METROPOLITAN SEWER DISTRICT of greater CINCINNATI

The Challenge of Wet Weather



Southwest Ohio receives
41 inches of rain
per year…

Results in approximately
11 billon gallons of overflow in a typical year

Led to a $3.2B Consent Decree to address the 200+ overflow points through:

- Strategic Separation
- Pipe Upsizing
- Dedicated WW Facilities

Led to Infrastructure Built Specifically for Wet Weather

Real-time Control Sites

High Rate Treatment Facilities

Stormwater Control Measures

Watershed Operations Division is Owner/Operator of these Sites

METROPOLITAN SEWER DISTRICT of greater CINCINNATI

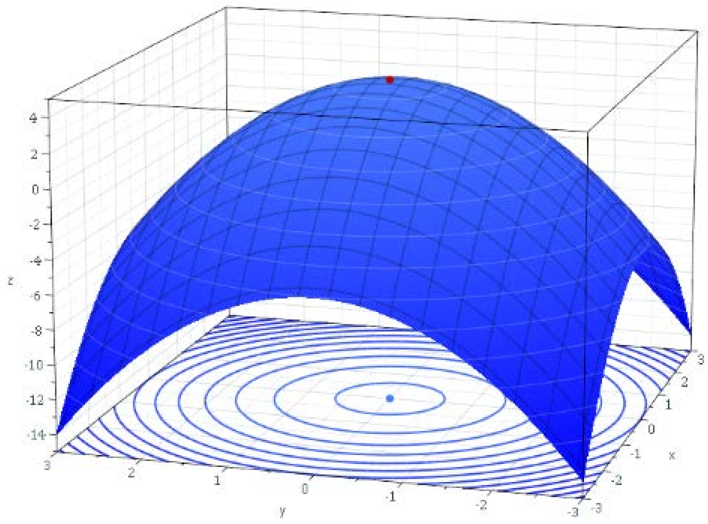
Affordability Concerns Spurred A New Approach

What if… we could use all available capacity in our pipes before overflows occurred?

What if… we could use an unused storage tank to reduce overflows many miles away?

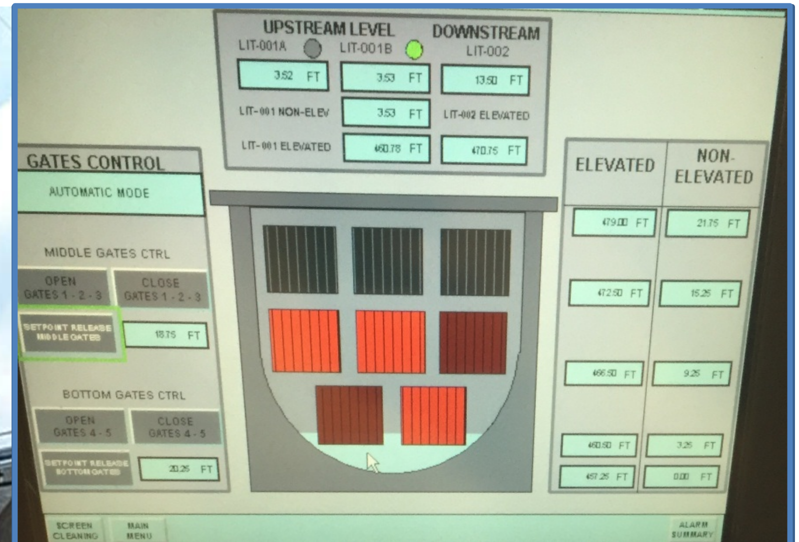
New Approach: Operational Optimization

Active control of the
collection system and
dedicated wet weather facilities
in real-time to
maximize utilization of existing
infrastructure
and
minimize releases to the environment



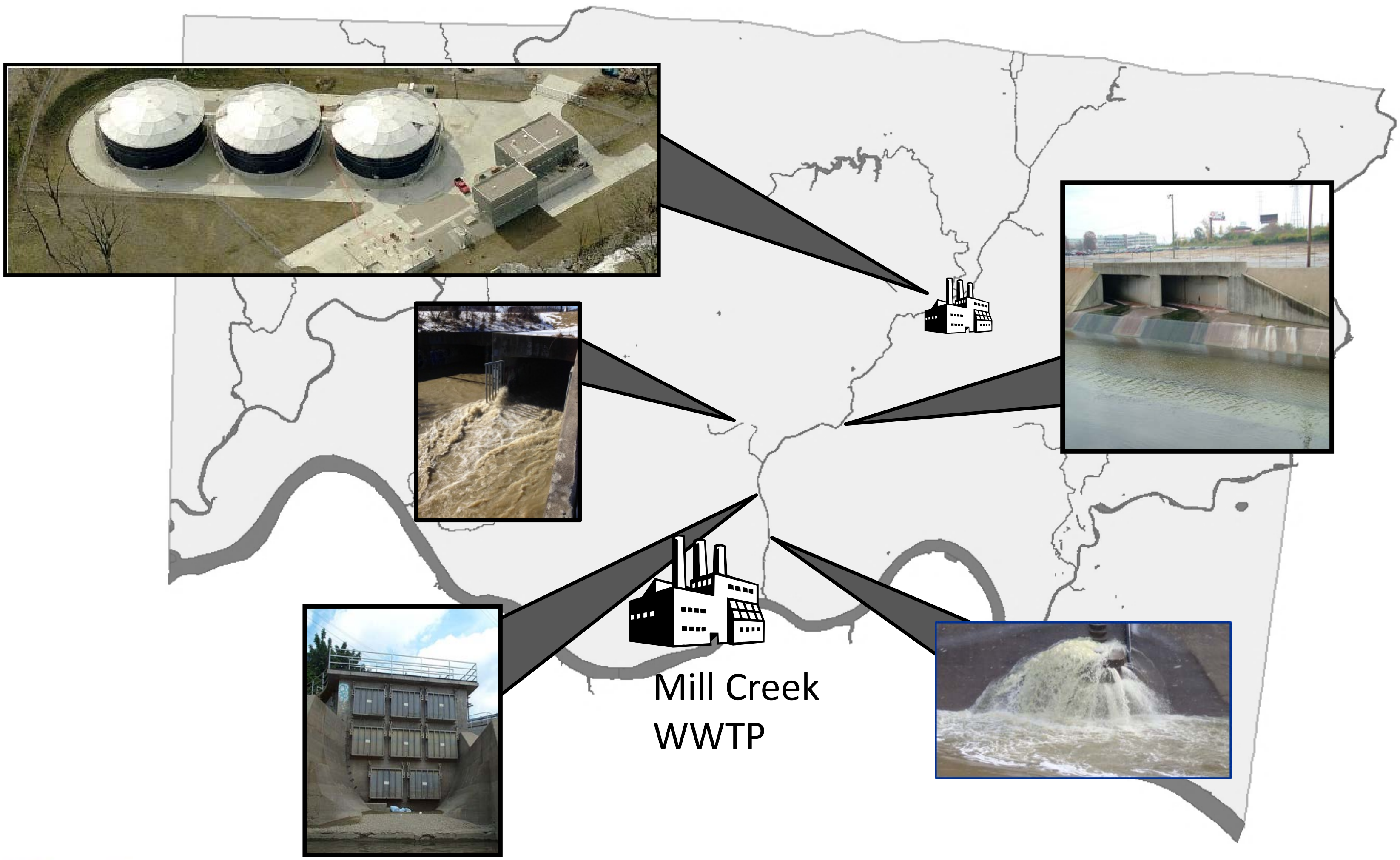
METROPOLITAN
SEWER DISTRICT
of greater
CINCINNATI

Each Wet Weather Facility Controlled Locally….

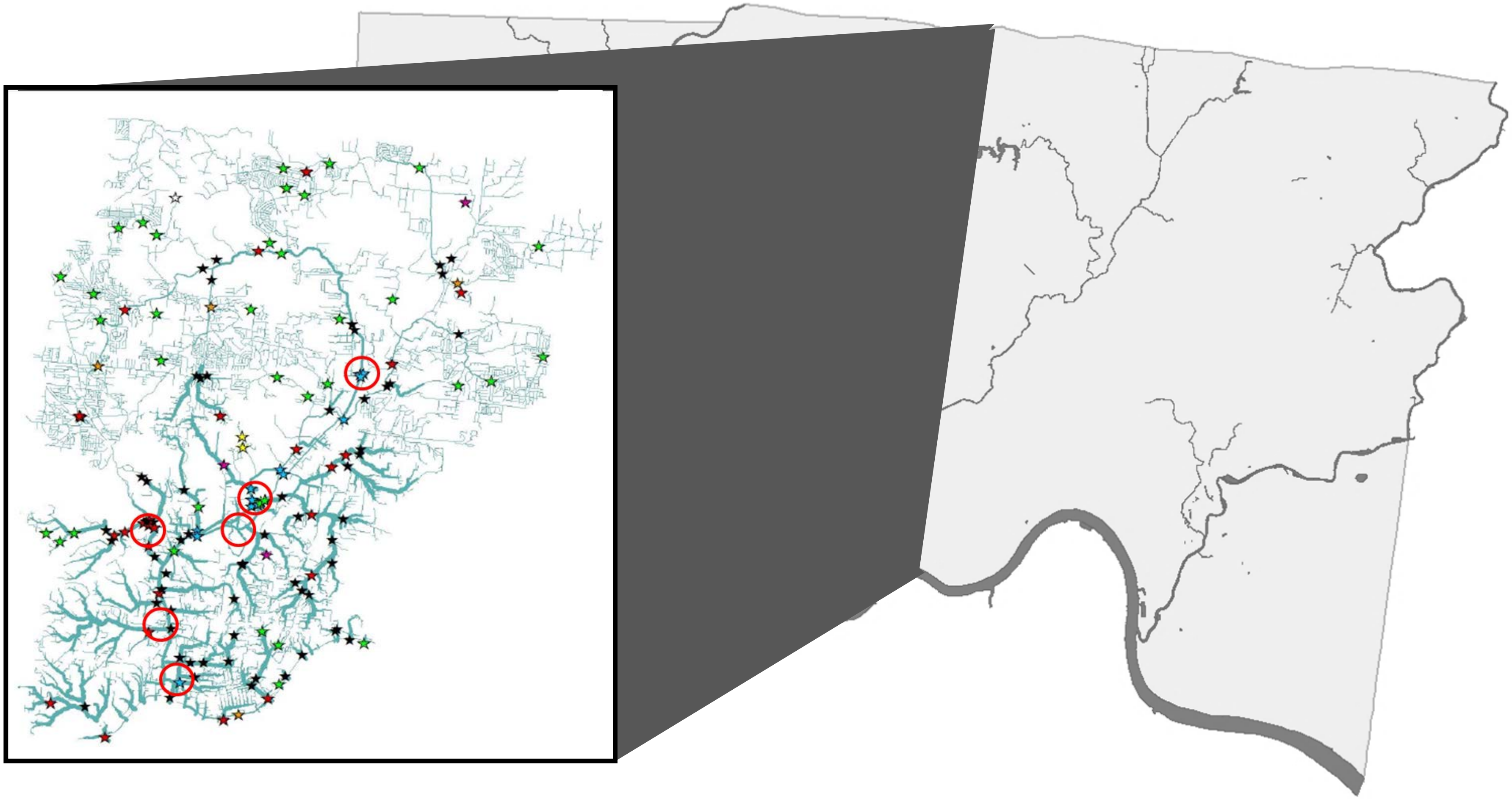


Local PLC connected to level sensors upstream and downstream of the gates to store flow without flooding residents and businesses

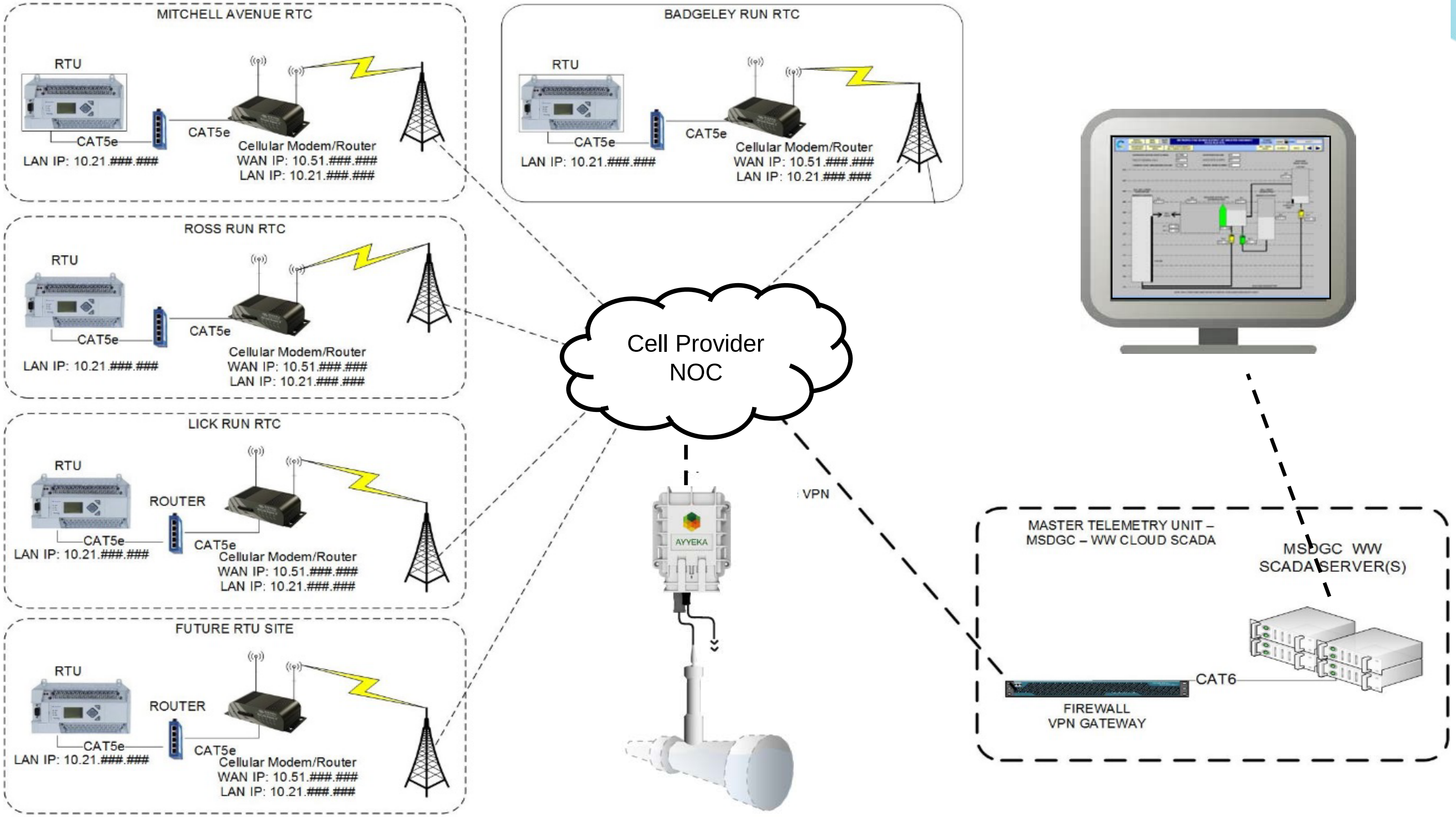
…but Located Across Hamilton County…



…and Needing Data from Widely-spread, Discrete Sensors



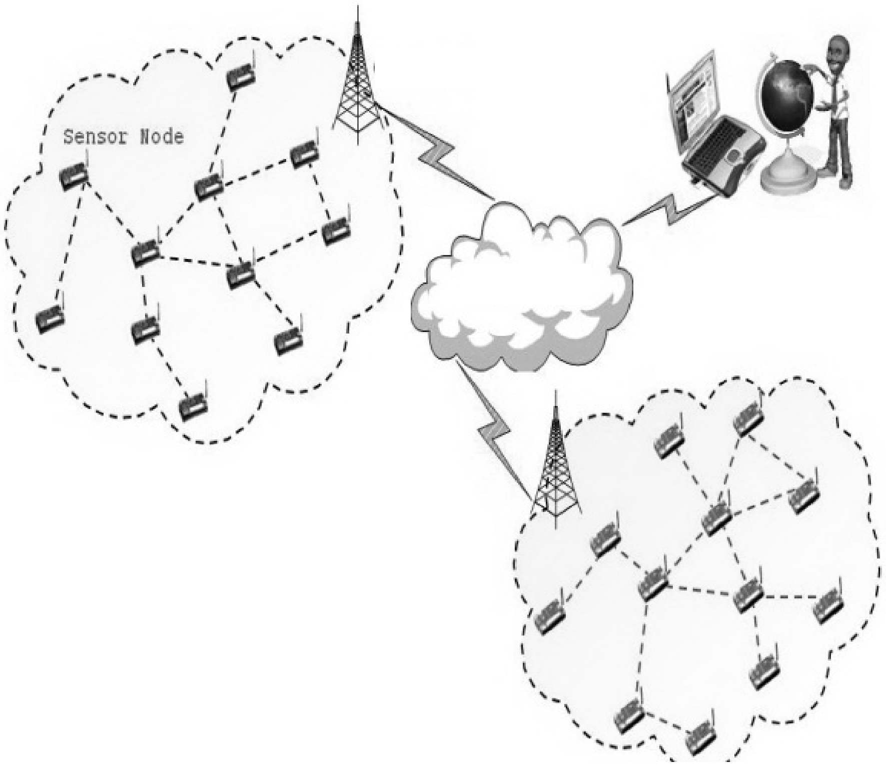
Led to a Cloud-based SCADA



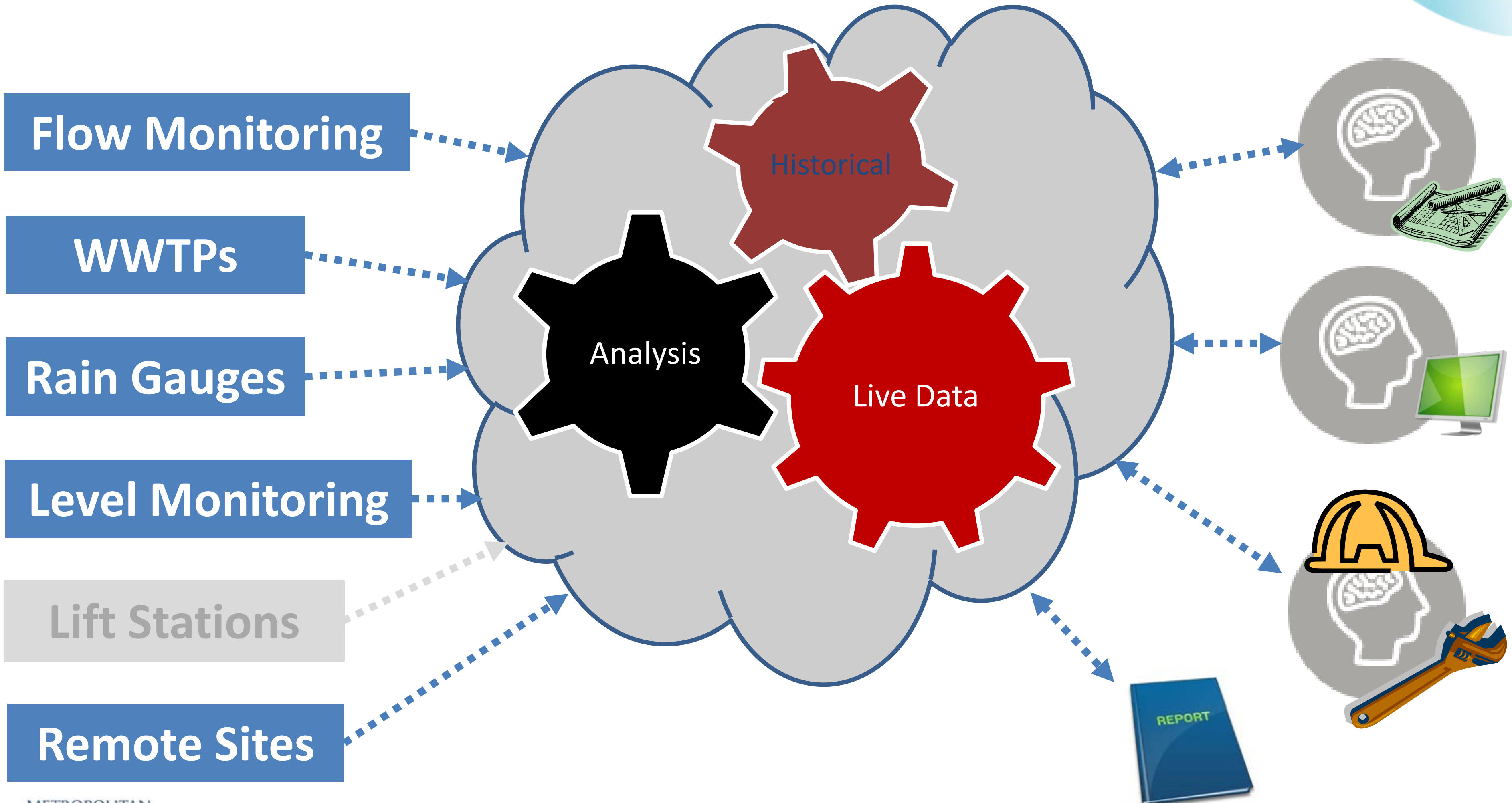
METROPOLITAN SEWER DISTRICT of greater CINCINNATI

Characteristics of Our SCADA System

- Virtual Infrastructure Maintained by MSD IT, Separate from Treatment Plant SCADA
- GE Intelligent Platforms' Proficy SCADA Software
- Data Transmitted via Cellular Technology through a Carrier-provided Private Network
- Secure User Access through Citrix

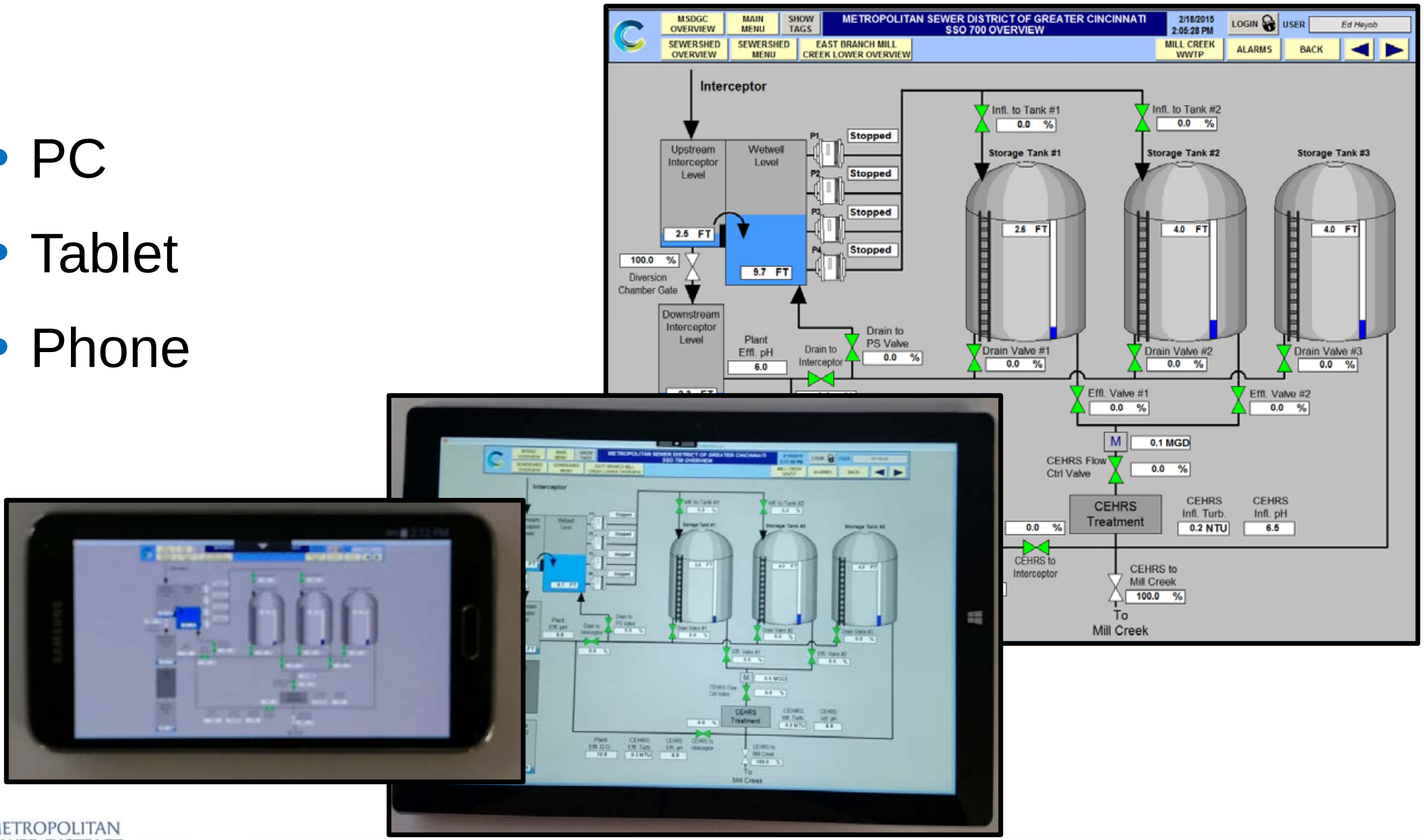


Central Data Repository



Secure Access via Multiple Platforms On- and Off-site

- PC
- Tablet
- Phone



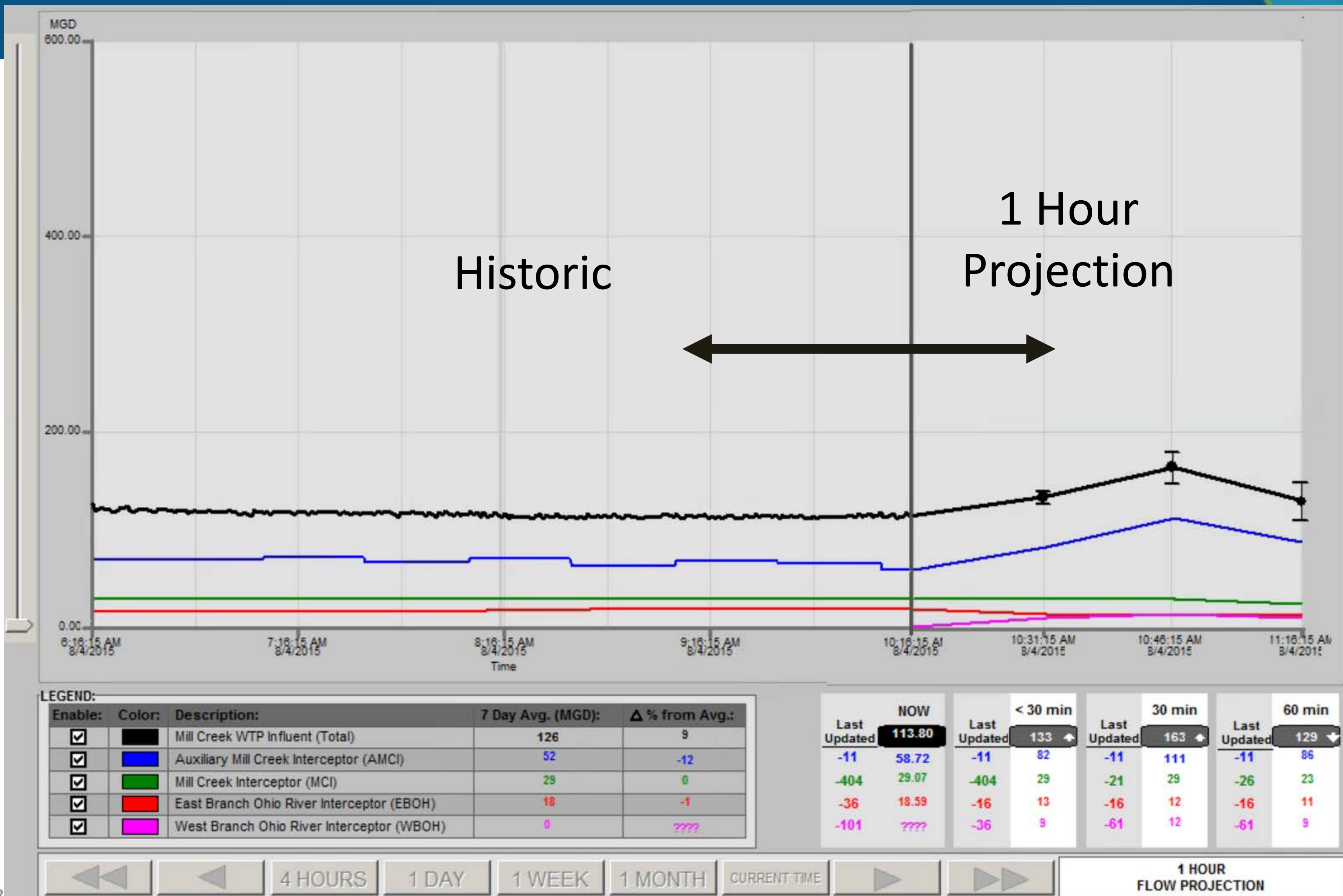
METROPOLITAN SEWER DISTRICT of greater CINCINNATI

“Smart Sewer” Achieves Results Without Additional Capacity

- Improves Treatment Plant Operations
- Reduces Overflows from the Collection System
- Improved Watershed Protection

METROPOLITAN SEWER DISTRICT of greater CINCINNATI

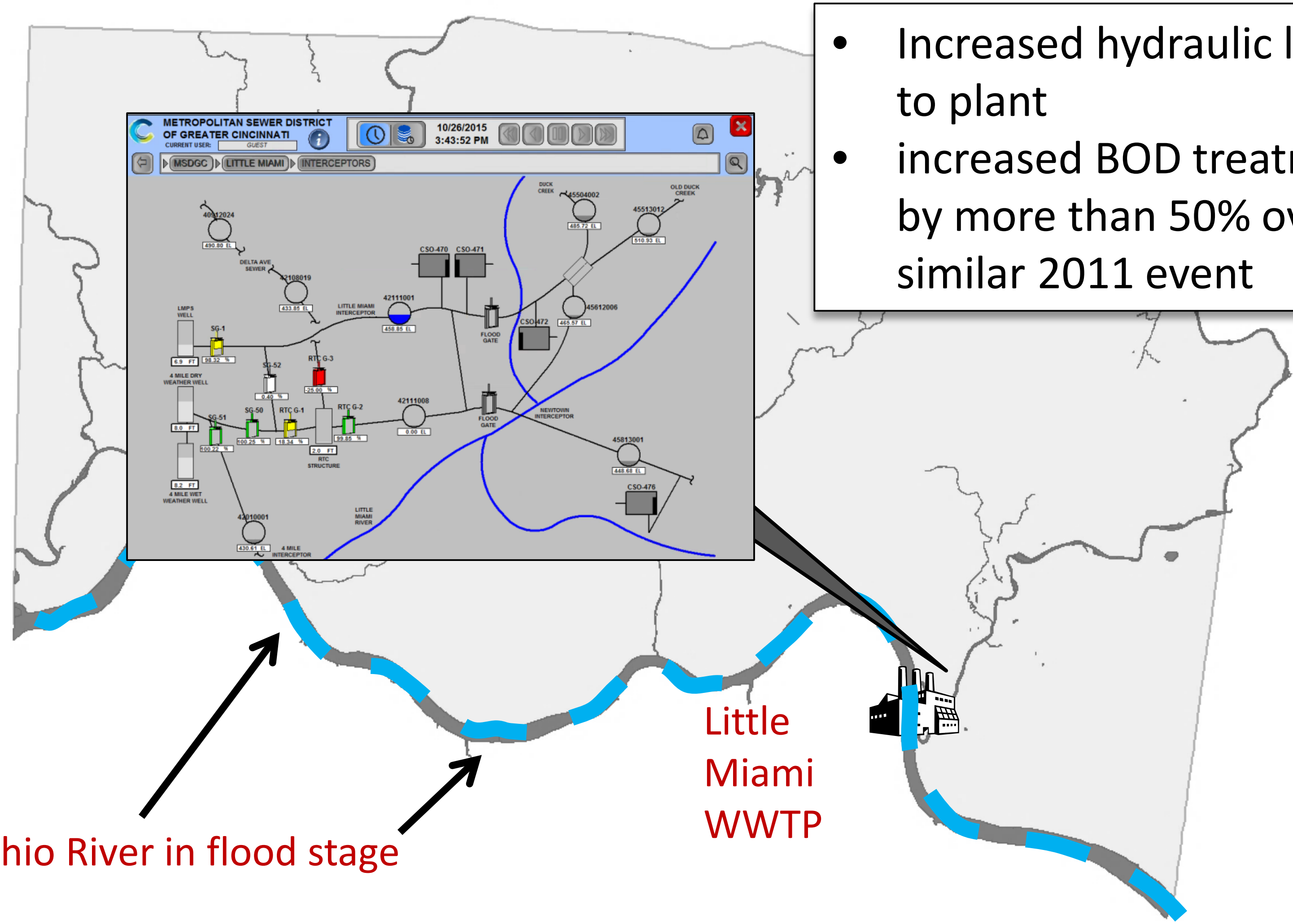
Improved TP Operations



Flow projections to MCTP

Improved TP Operations

- Increased hydraulic loadings to plant
- increased BOD treatment by more than 50% over similar 2011 event

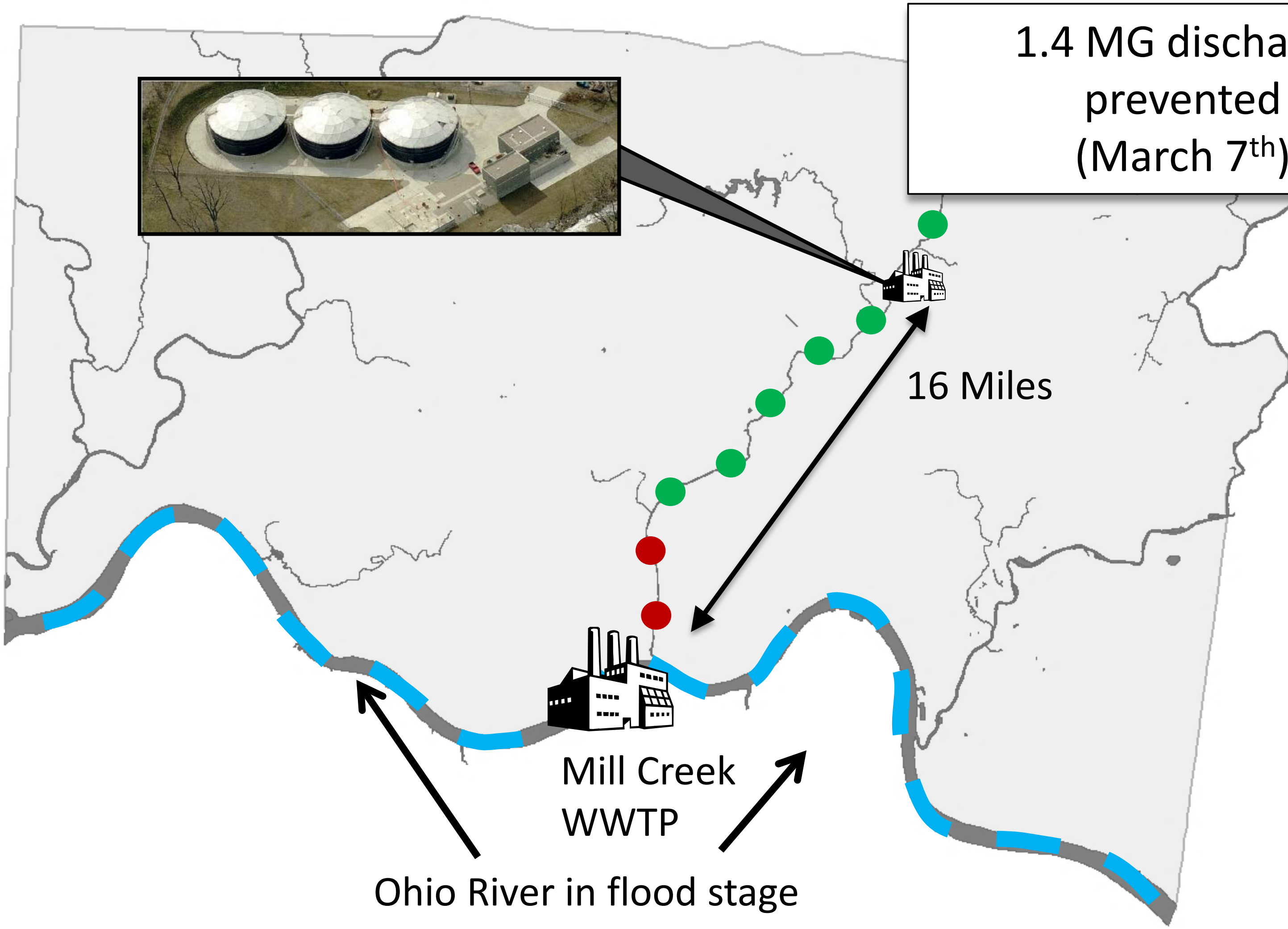


Higher Treatment Efficacy

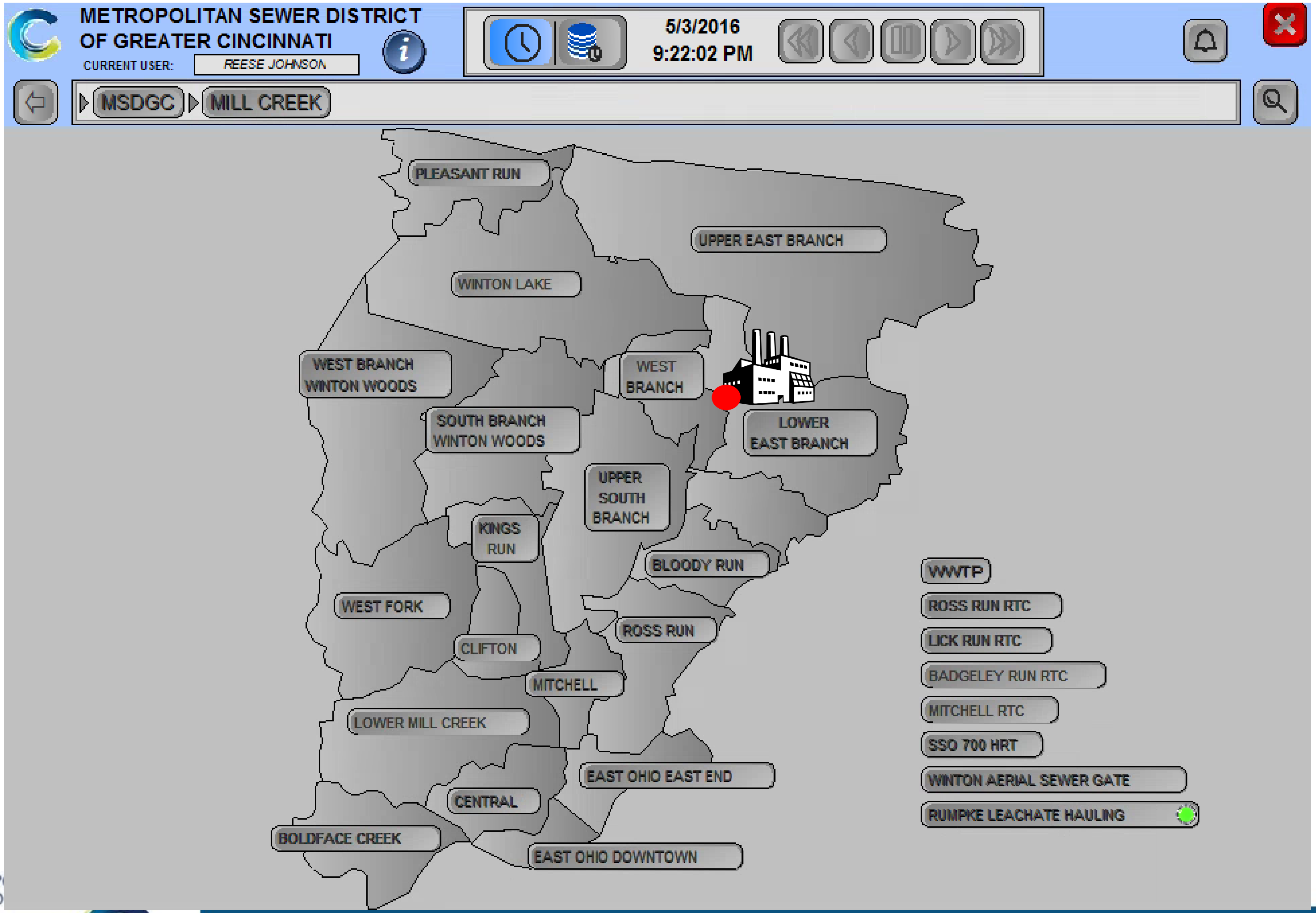
METRO SEWER DISTRICT of greater CINCINNATI

Reduced Overflows

1.4 MG discharge
prevented
(March 7th)

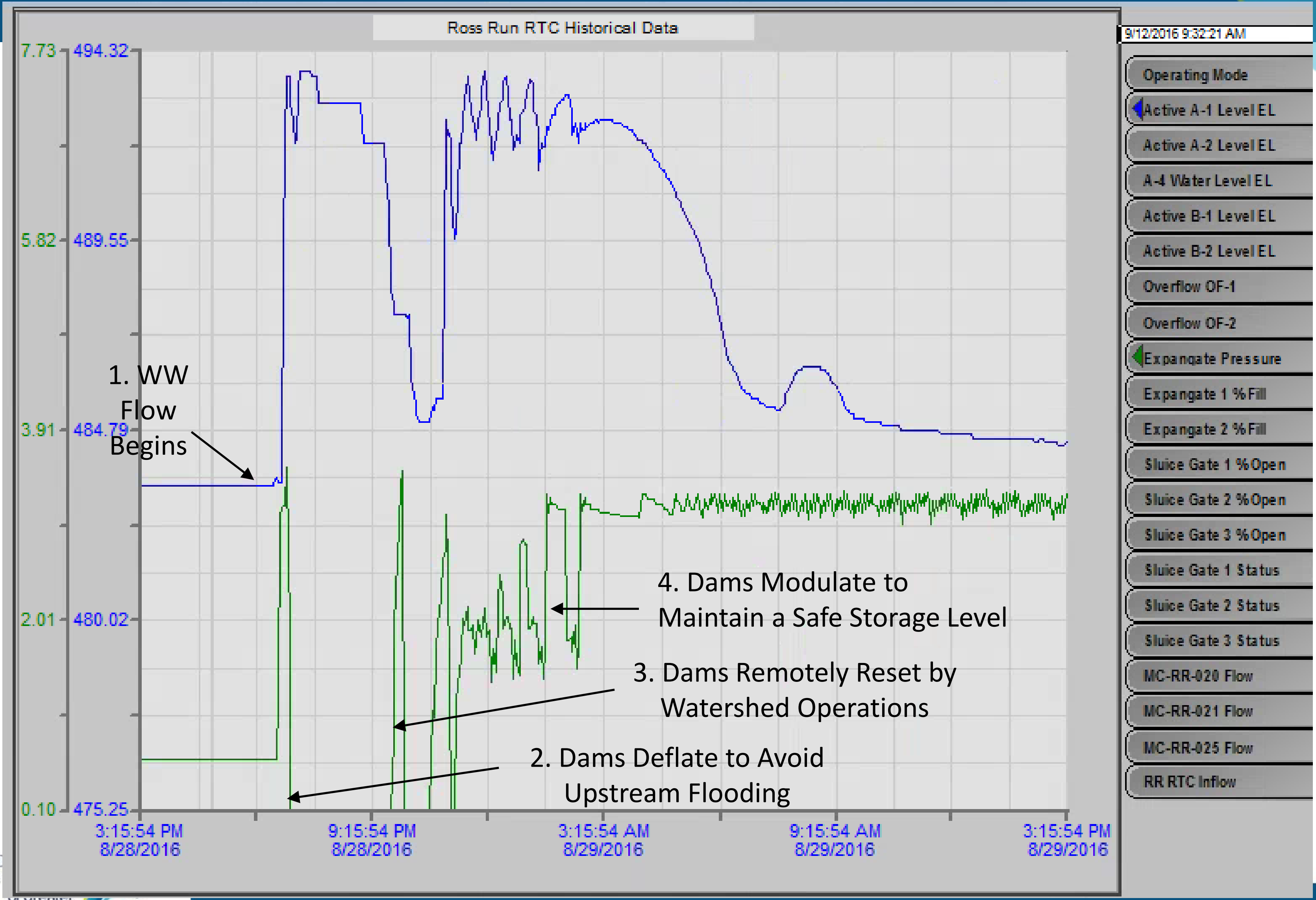


Reduced Overflows



Basin-wide Perspective

Reduced Overflows



METRO SEWER of greater CINCINNATI

Remote Reset of RTC Facility

Reduced Overflow Impact

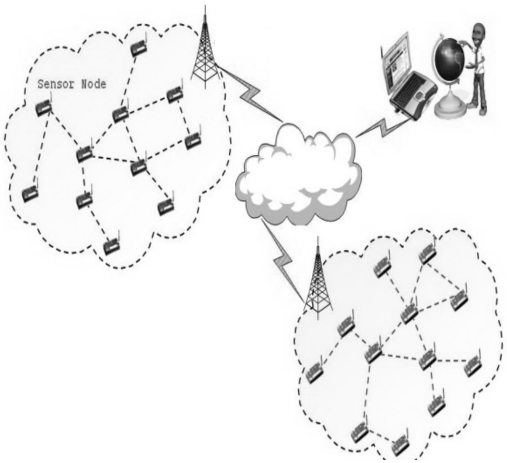
"Smart Sewer" Achieved Results Without Additional Capacity

- Improved Treatment Plant Operations
  - Projections of the Flow to Wastewater Treatment Plant
  - Higher Treatment Efficacy After Prolonged Wet Weather Event
- Improved Wet Weather Facility Operations
  - Leverage Distant Storage/Treatment Facility to Lessen Overflow
  - Remotely Reset Real-time Control Facility to Recover Mid-storm
- Improved Watershed Protection
  - Prioritize High-strength Wastewater for Treatment during Wet Weather

Summary

Challenges

- Needed lots of data
- Assets and sensors are spread across a wide area
- Complex, dynamic wastewater system

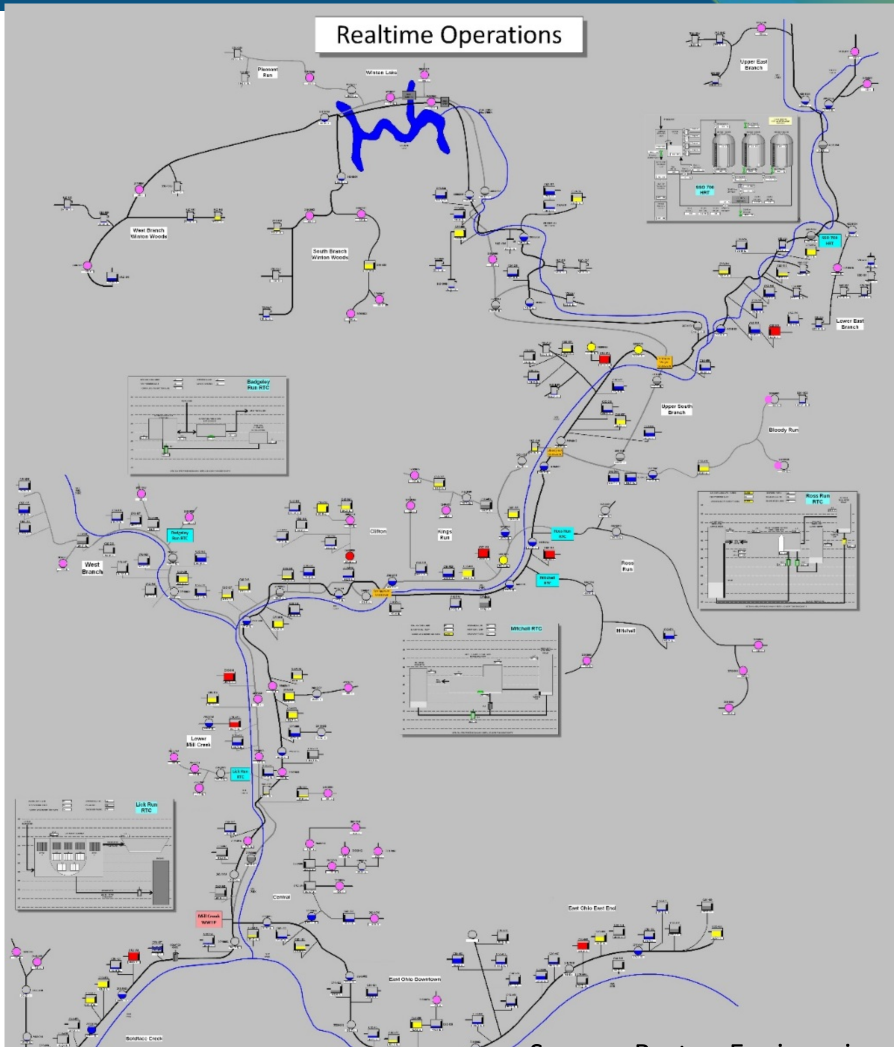


Innovative Technologies

- Cloud-based system
- Wireless communication with assets and sensors
- Automated analytics to alert us to abnormal conditions

Meeting the wet weather challenge with a cloud-based SCADA system has given us an innovative technology platform that lays the foundation for watershed-level coordinated control of our assets and has already improved operational decisions.

MSDGC's Wet Weather SCADA System



Source: Barton Engineering

METROPOLITAN SEWER DISTRICT OF GREATER CINCINNATI

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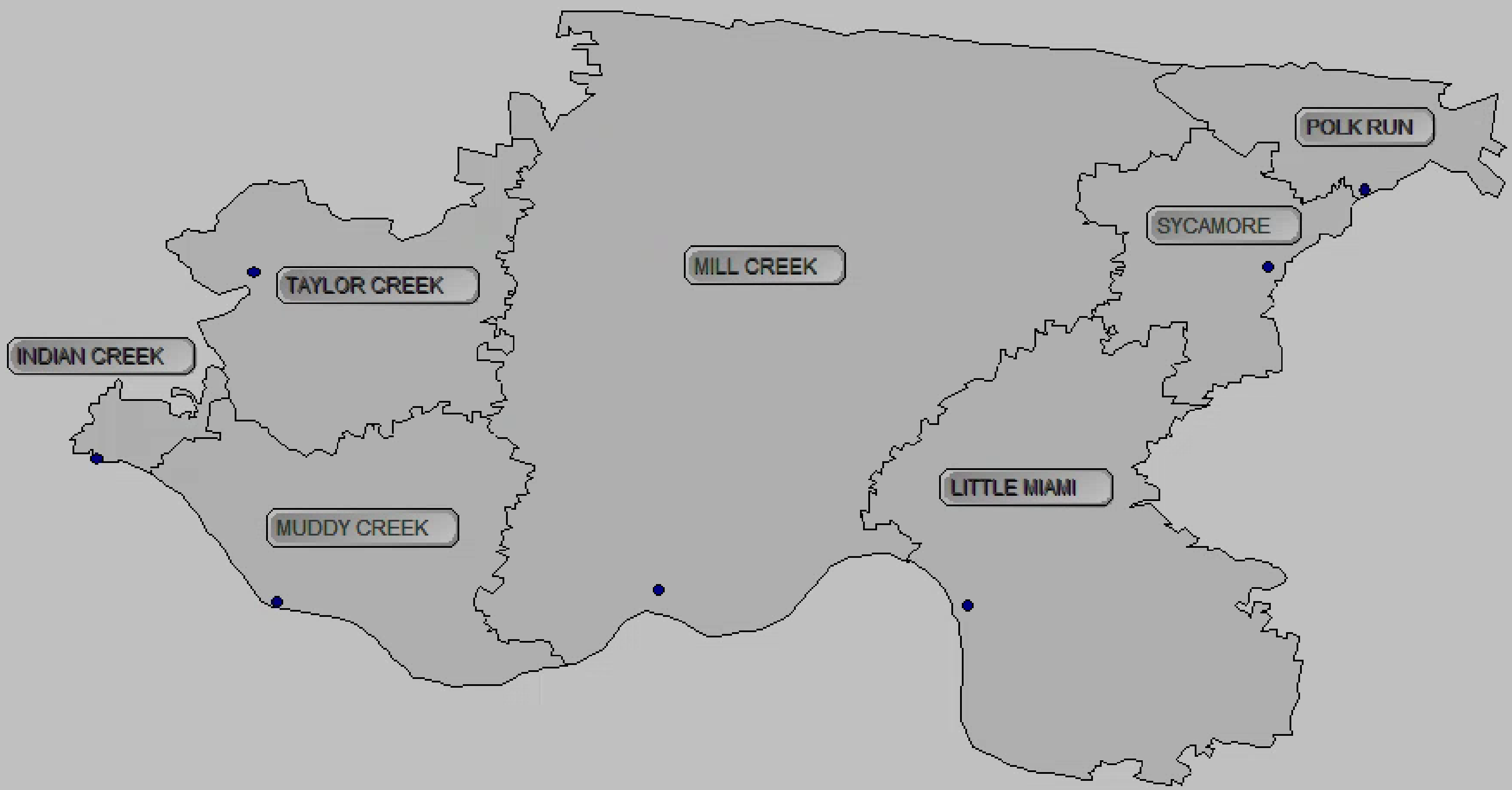
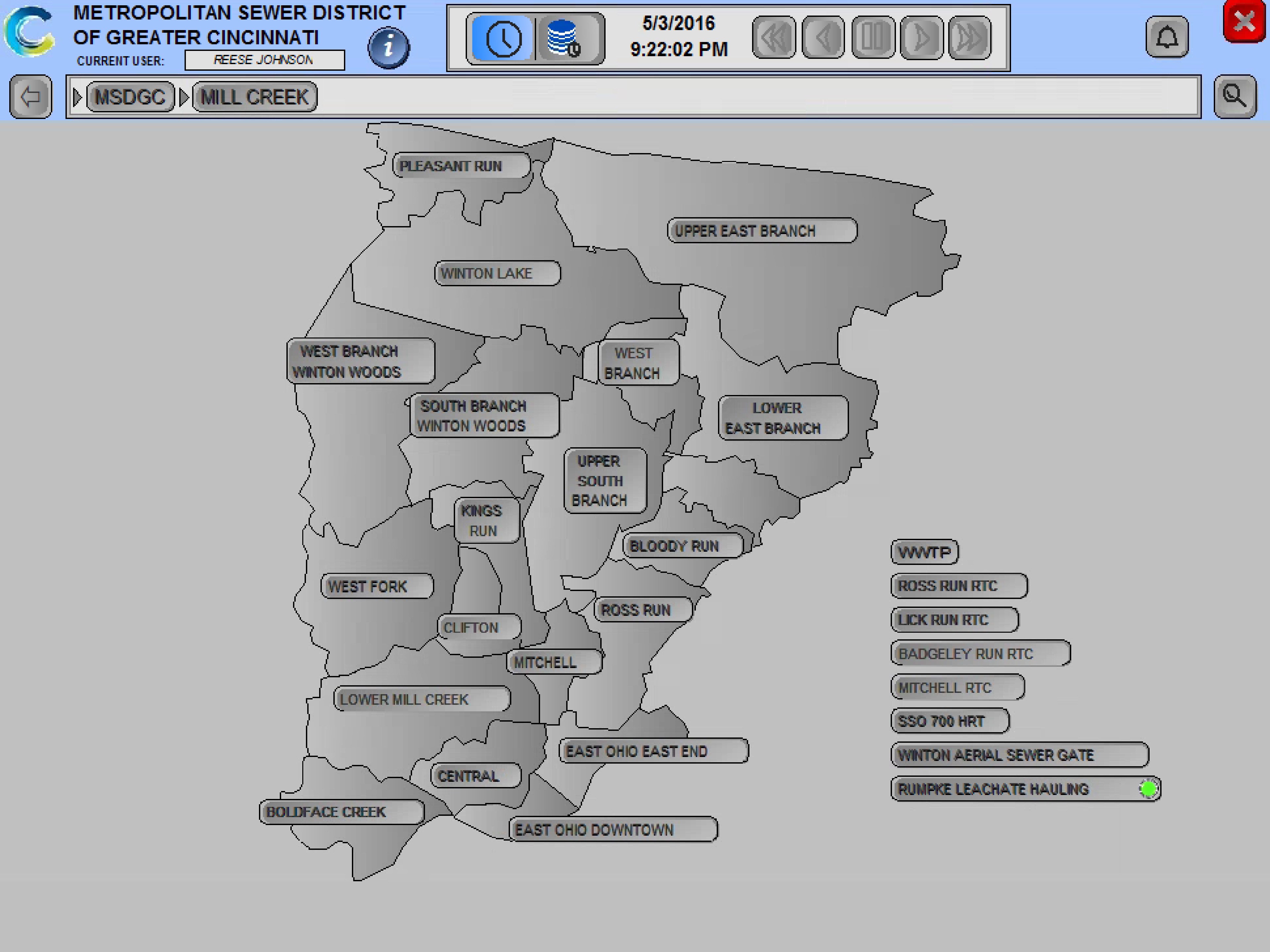
5/3/2016
4:10:37 PM

MSDGC




METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
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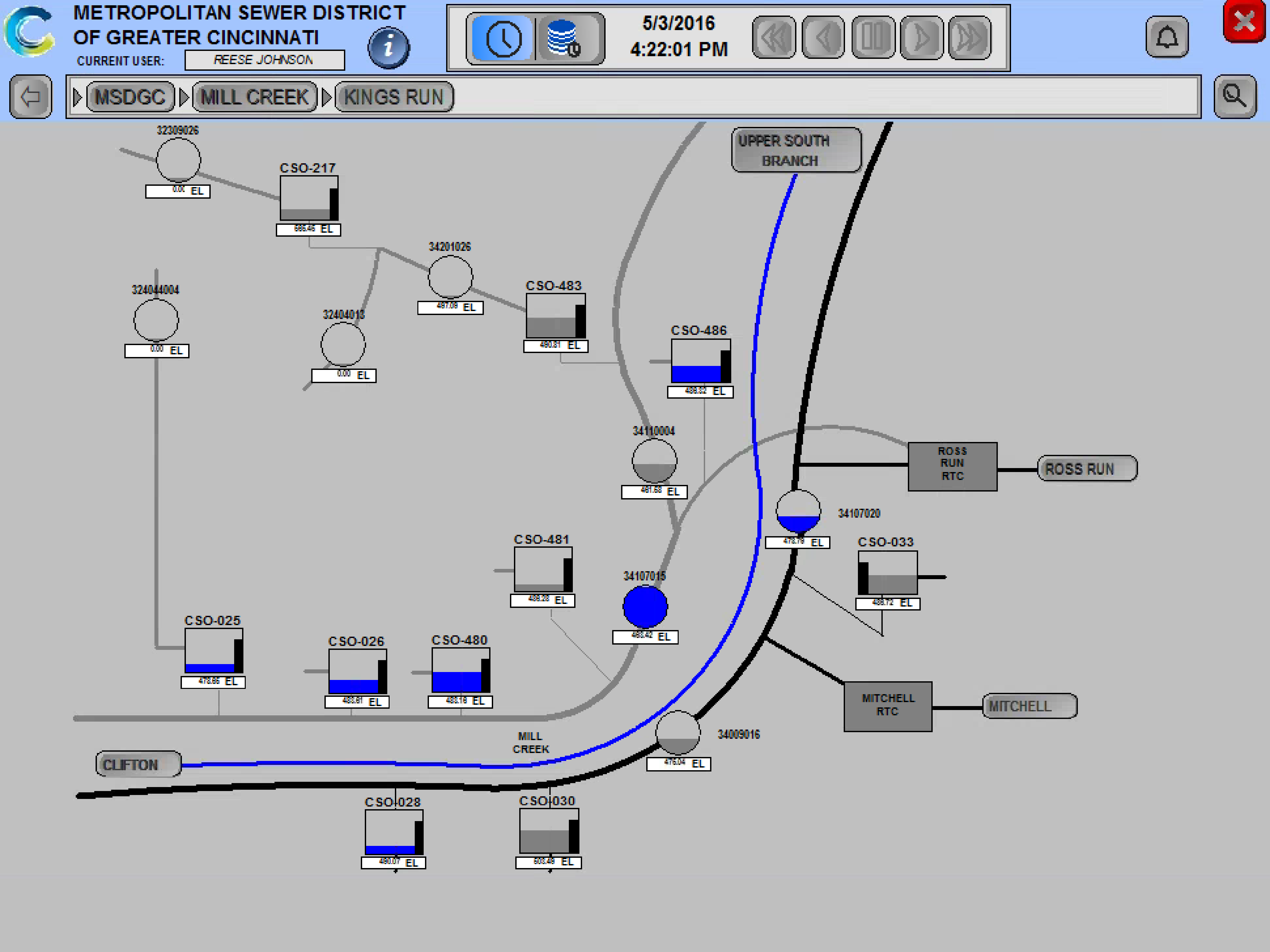
REESE JOHNSON
5/3/2016
9:22:02 PM
MSDGC
MILL CREEK
PLEASANT RUN
UPPER EAST BRANCH
WINTON LAKE
WEST BRANCH WINTON WOODS
WEST BRANCH
SOUTH BRANCH WINTON WOODS
LOWER EAST BRANCH
UPPER SOUTH BRANCH
KINGS RUN
BLOODY RUN
WEST FORK
ROSS RUN
CLIFTON
MITCHELL
LOWER MILL CREEK
EAST OHIO EAST END
CENTRAL
BOLDFACE CREEK
EAST OHIO DOWNTOWN
WWTP
ROSS RUN RTC
LICK RUN RTC
BADGELEY RUN RTC
MITCHELL RTC
SSO 700 HRT
WINTON AERIAL SEWER GATE
RUMPKE LEACHATE HAULING


METROPOLITAN SEWER DISTRICT OF GREATER CINCINNATI
CURRENT USER:
REESE JOHNSON
5/3/2016
4:22:01 PM
MSDGC
MILL CREEK
KINGS RUN
UPPER SOUTH BRANCH
32309026
CSO-217
34201026
324044004
32404013
CSO-483
CSO-486
34110004
ROSS RUN RTC
ROSS RUN
34107020
CSO-481
34107015
CSO-033
CSO-025
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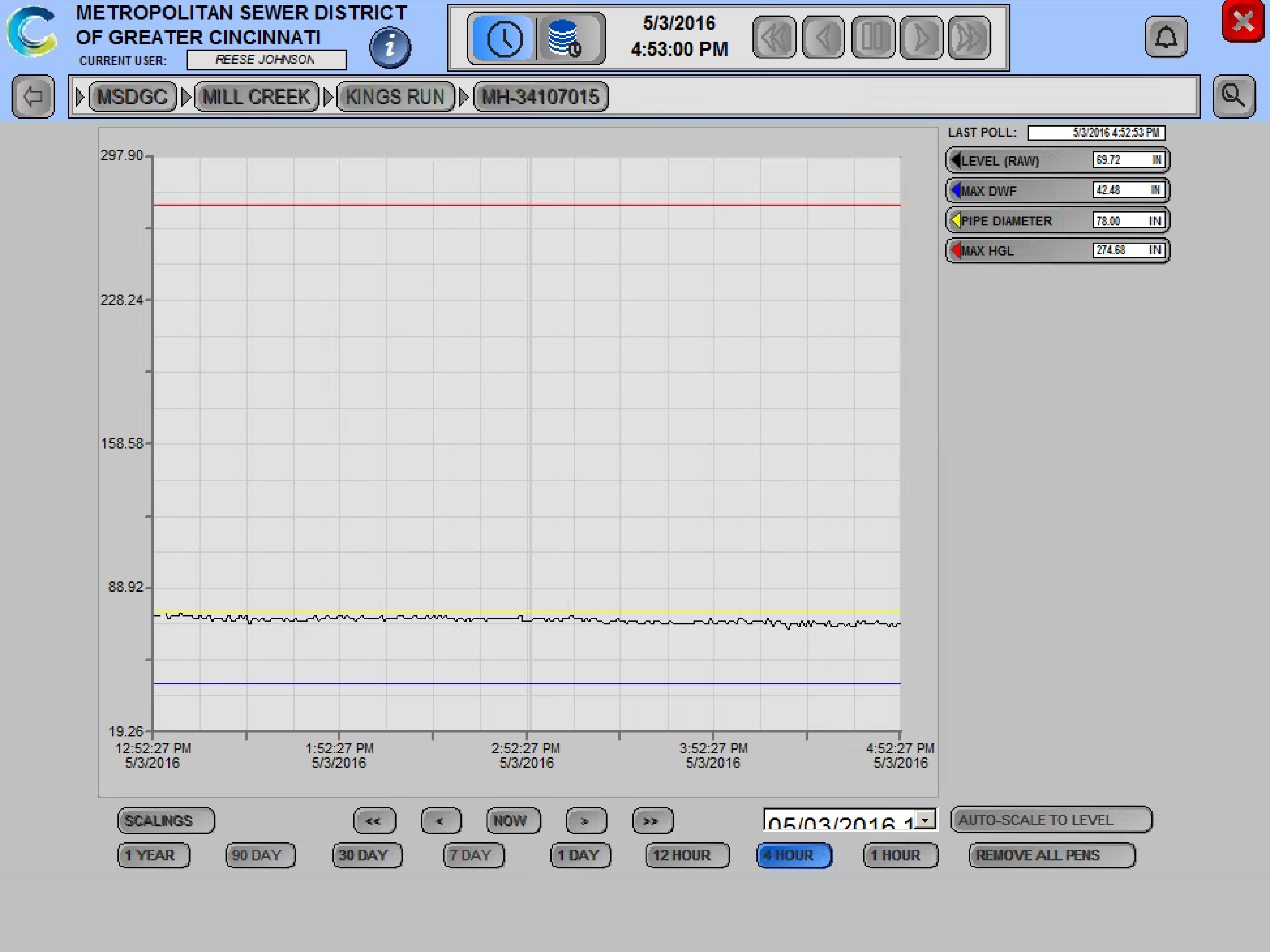
CSO-480
MITCHELL RTC
MITCHELL
34009016
MILL CREEK
CLIFTON
CSO-028
CSO-030
EL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OF GREATER CINCINNATI
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KINGS RUN
MH-34107015
LAST POLL:
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MAX DWF 42.48 IN
PIPE DIAMETER 78.00 IN
MAX HGL 274.68 IN
297.90
228.24
158.58
88.92
19.26
12:52:27 PM 5/3/2016
1:52:27 PM 5/3/2016
2:52:27 PM 5/3/2016
3:52:27 PM 5/3/2016
4:52:27 PM 5/3/2016
SCALINGS
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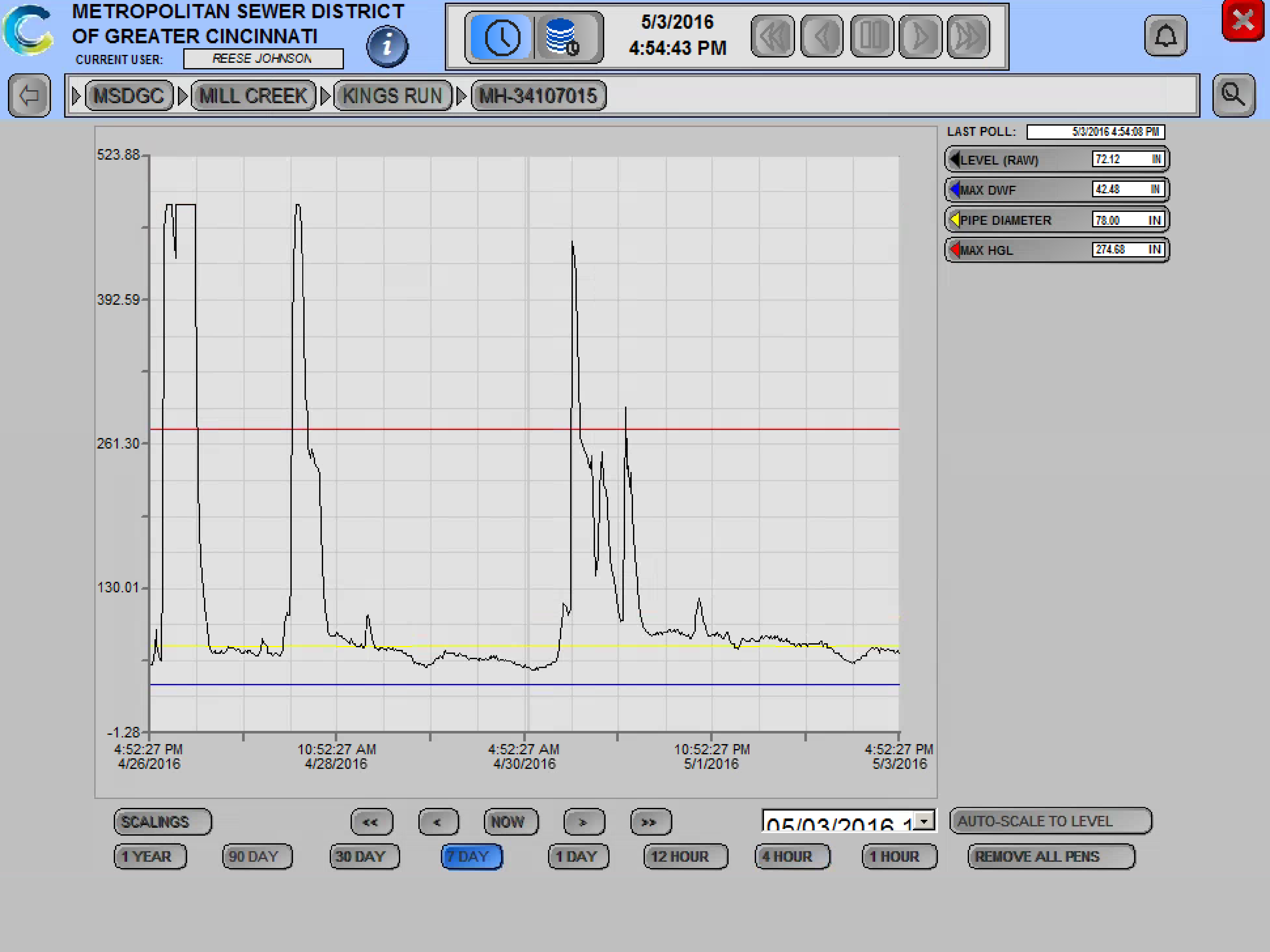
05/03/2016 1
AUTO-SCALE TO LEVEL
1 YEAR
90 DAY
30 DAY
7 DAY
1 DAY
12 HOUR
4 HOUR
1 HOUR
REMOVE ALL PENS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5/3/2016
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KINGS RUN
MH-34107015
LAST POLL:
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MAX DWF 42.48 IN
PIPE DIAMETER 78.00 IN
MAX HGL 274.68 IN
523.88
392.59
261.30
130.01
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4:52:27 PM 4/26/2016
10:52:27 AM 4/28/2016
4:52:27 AM 4/30/2016
10:52:27 PM 5/1/2016
4:52:27 PM 5/3/2016
SCALINGS
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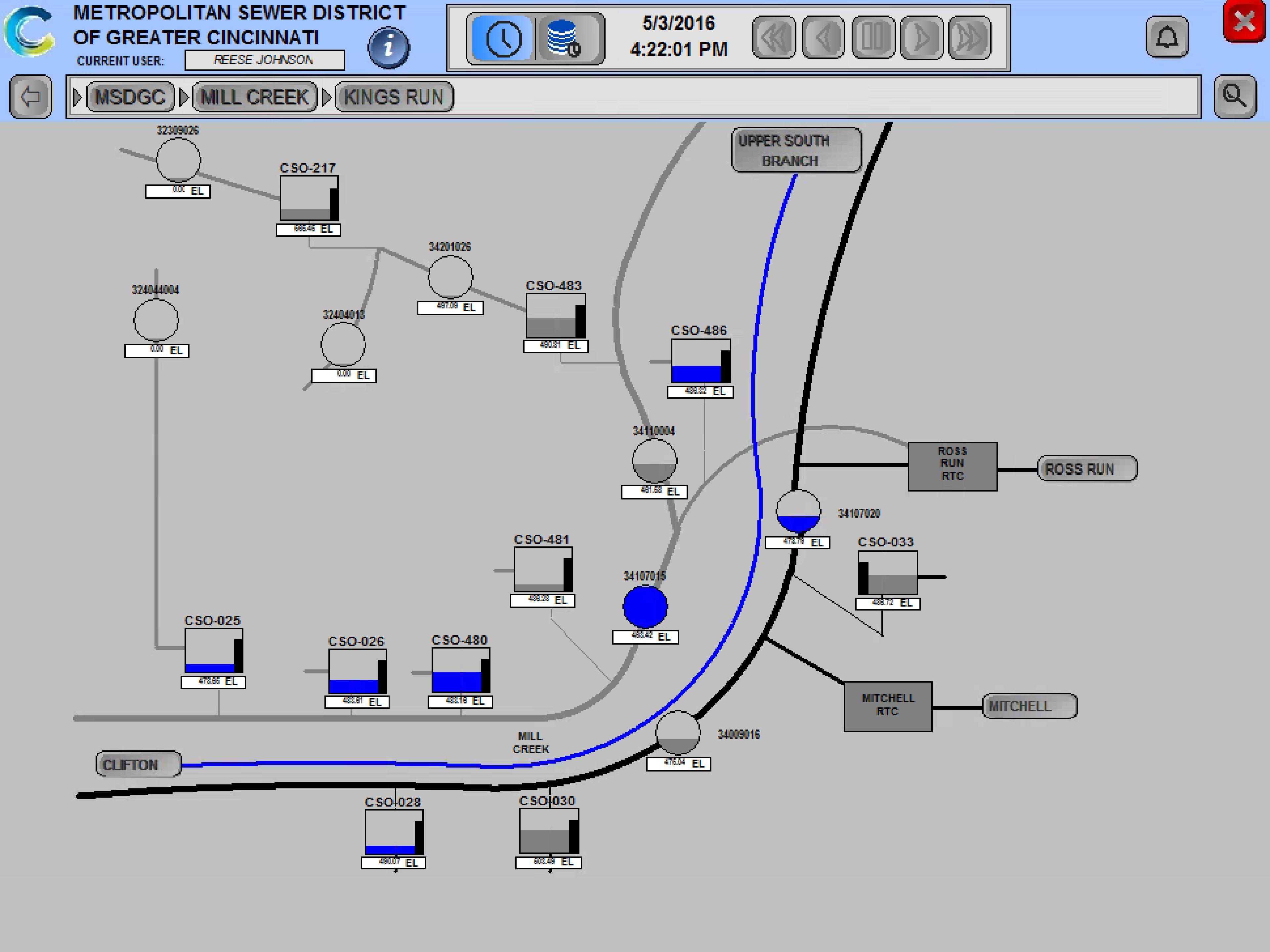
AUTO-SCALE TO LEVEL
1 YEAR
90 DAY
30 DAY
7 DAY
1 DAY
12 HOUR
4 HOUR
1 HOUR
REMOVE ALL PENS


METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
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5/3/2016
4:22:01 PM
MSDGC
MILL CREEK
KINGS RUN
32309026
CSO-217
34201026
324044004
32404013
CSO-483
UPPER SOUTH BRANCH
CSO-486
34110004
ROSS RUN RTC
ROSS RUN
34107020
CSO-481
34107015
CSO-033
CSO-025
CSO-026
CSO-480
MITCHELL RTC
MITCHELL
34009016
MILL CREEK
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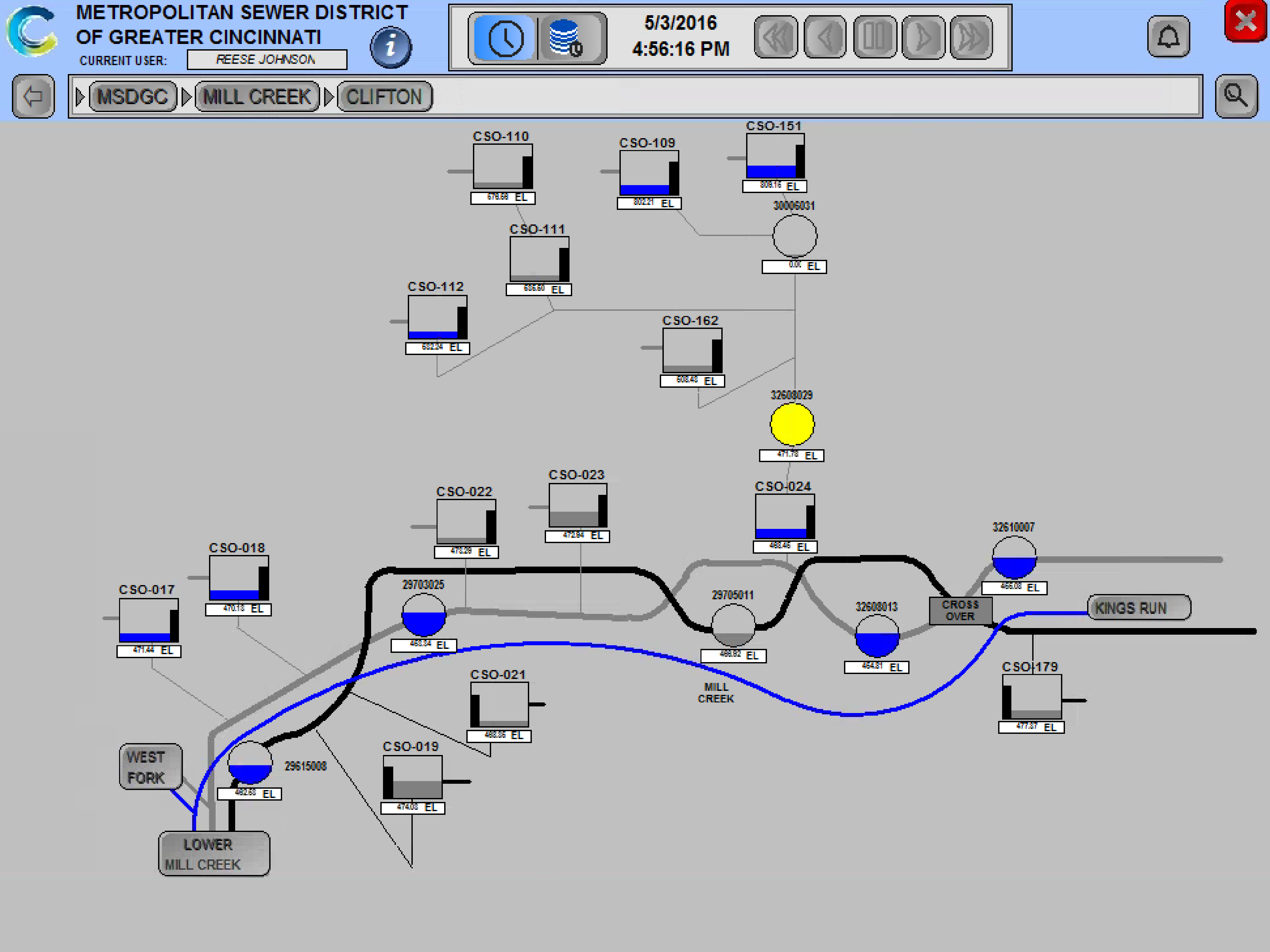
CSO-028
CSO-030
EL



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5/3/2016
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MILL CREEK
CLIFTON
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CSO-109
CSO-151
30006031
CSO-111
CSO-112
CSO-162
32608029
CSO-022
CSO-023
CSO-024
32610007
CSO-018
CSO-017
29703025
29705011
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CROSS OVER
KINGS RUN
CSO-179
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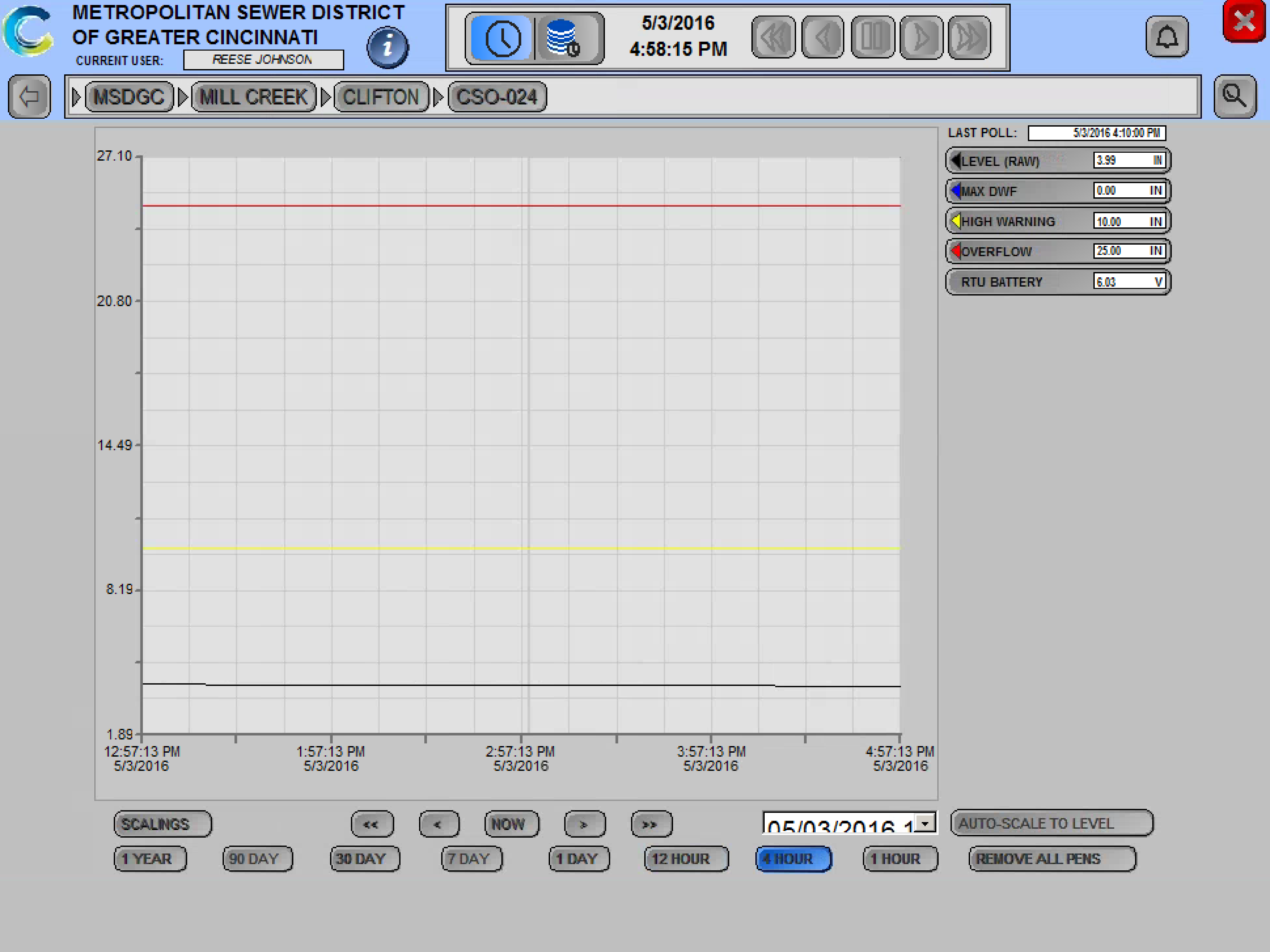
MILL CREEK
CSO-019
29615008
WEST FORK
LOWER MILL CREEK
EL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OF GREATER CINCINNATI
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CLIFTON
CSO-024
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HIGH WARNING
10.00
IN
OVERFLOW
25.00
IN
RTU BATTERY
6.03
V
27.10
20.80
14.49
8.19
1.89
12:57:13 PM 5/3/2016
1:57:13 PM 5/3/2016
2:57:13 PM 5/3/2016
3:57:13 PM 5/3/2016
4:57:13 PM 5/3/2016
SCALINGS
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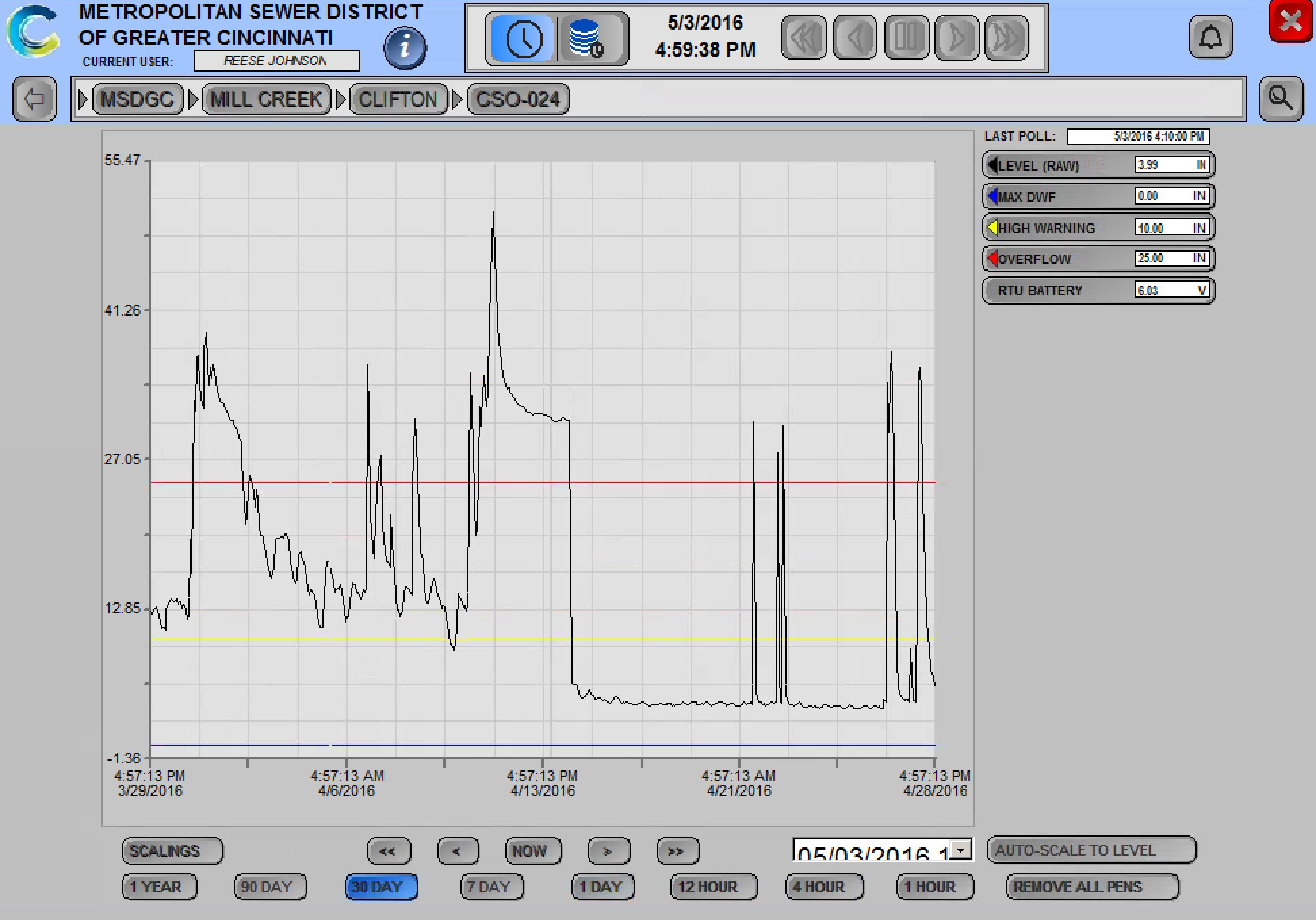
AUTO-SCALE TO LEVEL
1 YEAR
90 DAY
30 DAY
7 DAY
1 DAY
12 HOUR
4 HOUR
1 HOUR
REMOVE ALL PENS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CLIFTON
CSO-024
LAST POLL:
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MAX DWF 0.00 IN
HIGH WARNING 10.00 IN
OVERFLOW 25.00 IN
RTU BATTERY 6.03 V
55.47
41.26
27.05
12.85
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4:57:13 AM 4/6/2016
4:57:13 PM 4/13/2016
4:57:13 AM 4/21/2016
4:57:13 PM 4/28/2016
SCALINGS
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>>
AUTO-SCALE TO LEVEL
1 YEAR
90 DAY
30 DAY
7 DAY
1 DAY
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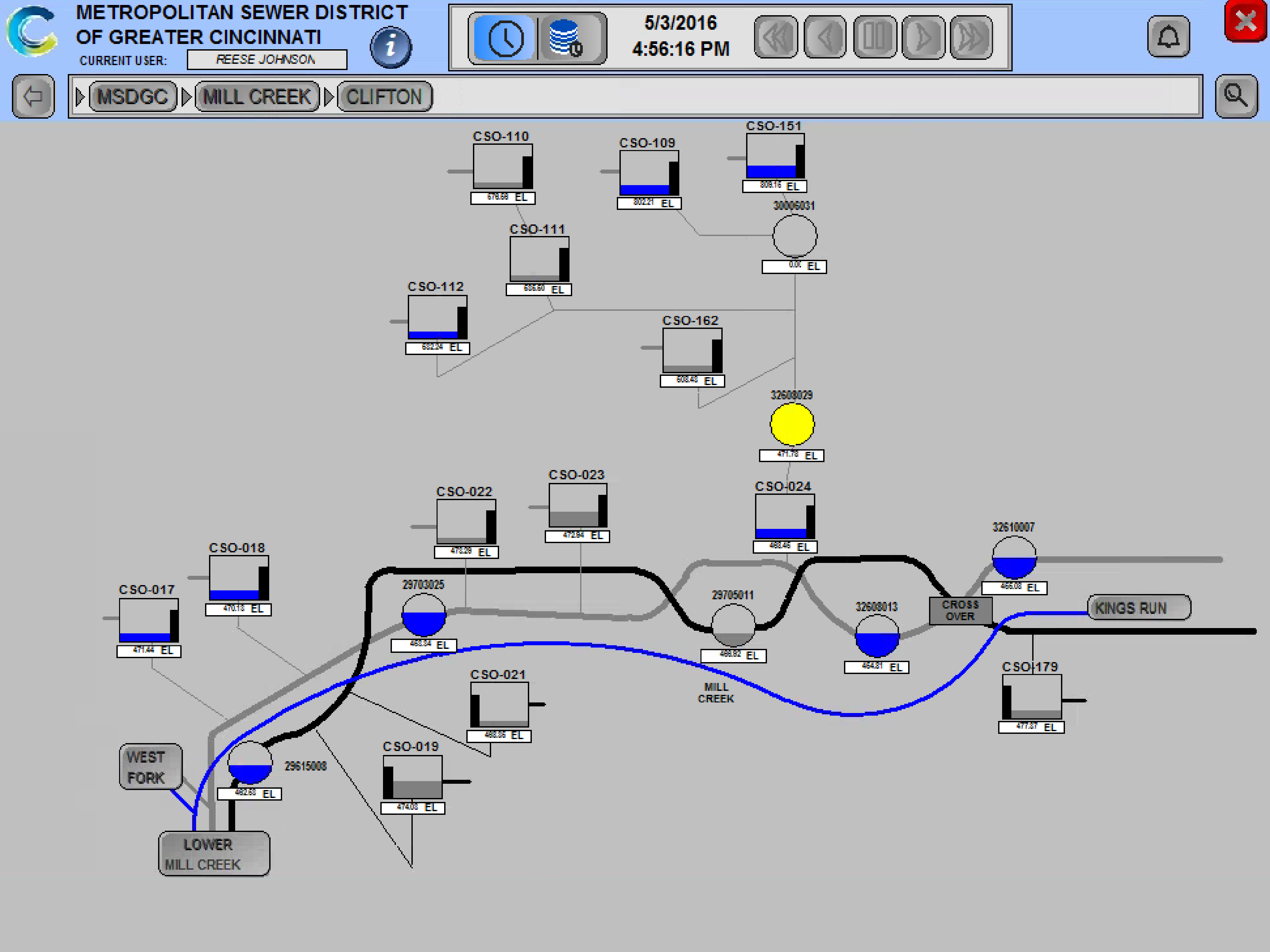
1 HOUR
REMOVE ALL PENS


METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
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5/3/2016
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MILL CREEK
CLIFTON
CSO-110
CSO-109
CSO-151
30006031
CSO-111
CSO-112
CSO-162
32608029
CSO-022
CSO-023
CSO-024
32610007
CSO-018
CSO-017
29703025
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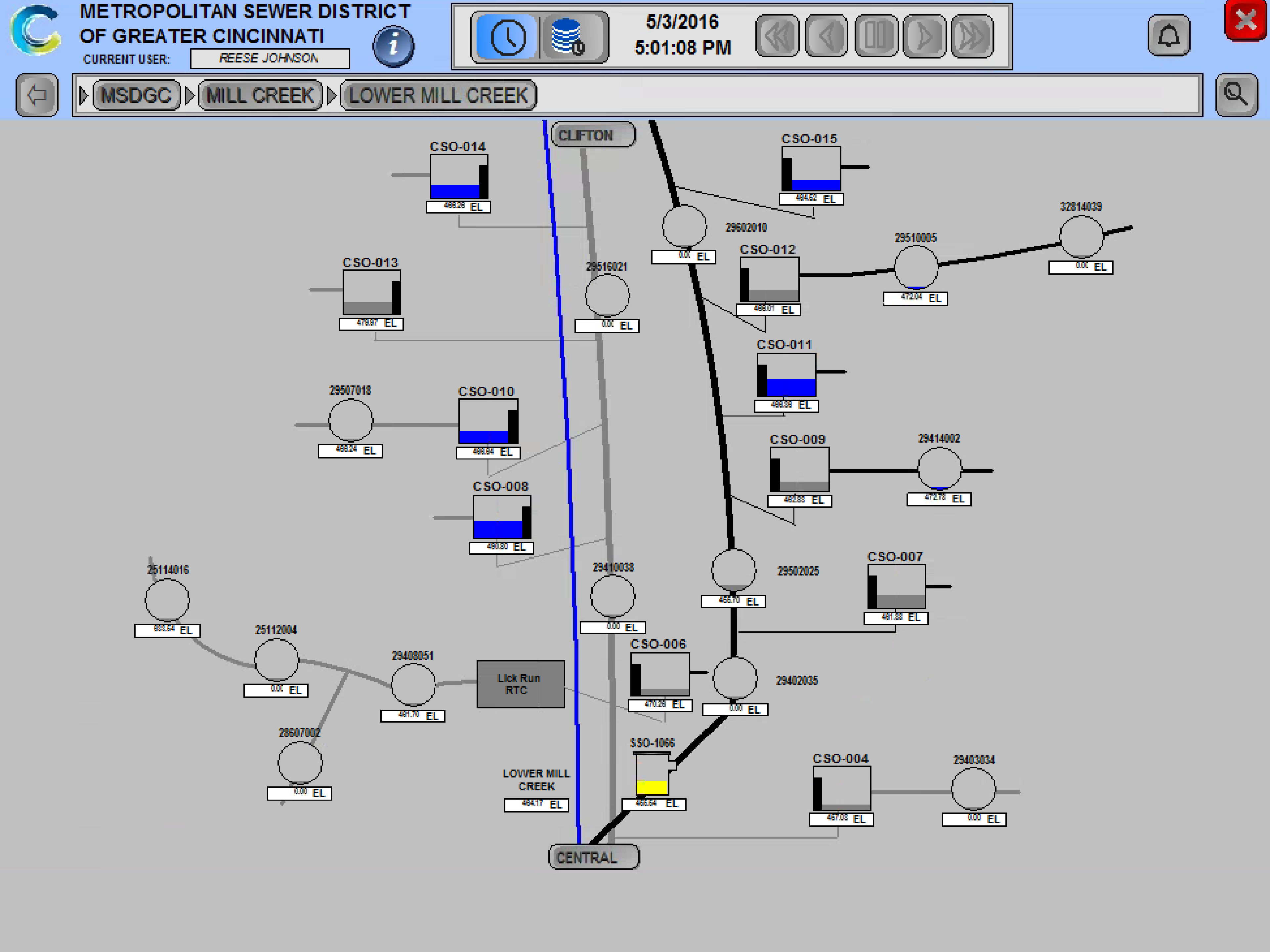
32608013
CROSS OVER
KINGS RUN
CSO-021
MILL CREEK
CSO-179
CSO-019
WEST FORK
29615008
LOWER MILL CREEK


METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
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5/3/2016
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MILL CREEK
LOWER MILL CREEK
CLIFTON
CSO-014
CSO-015
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CSO-012
29510005
CSO-013
29516021
CSO-011
29507018
CSO-010
CSO-009
29414002
CSO-008
25114016
29410038
29502025
CSO-007
25112004
29408051
Lick Run
RTC
CSO-006
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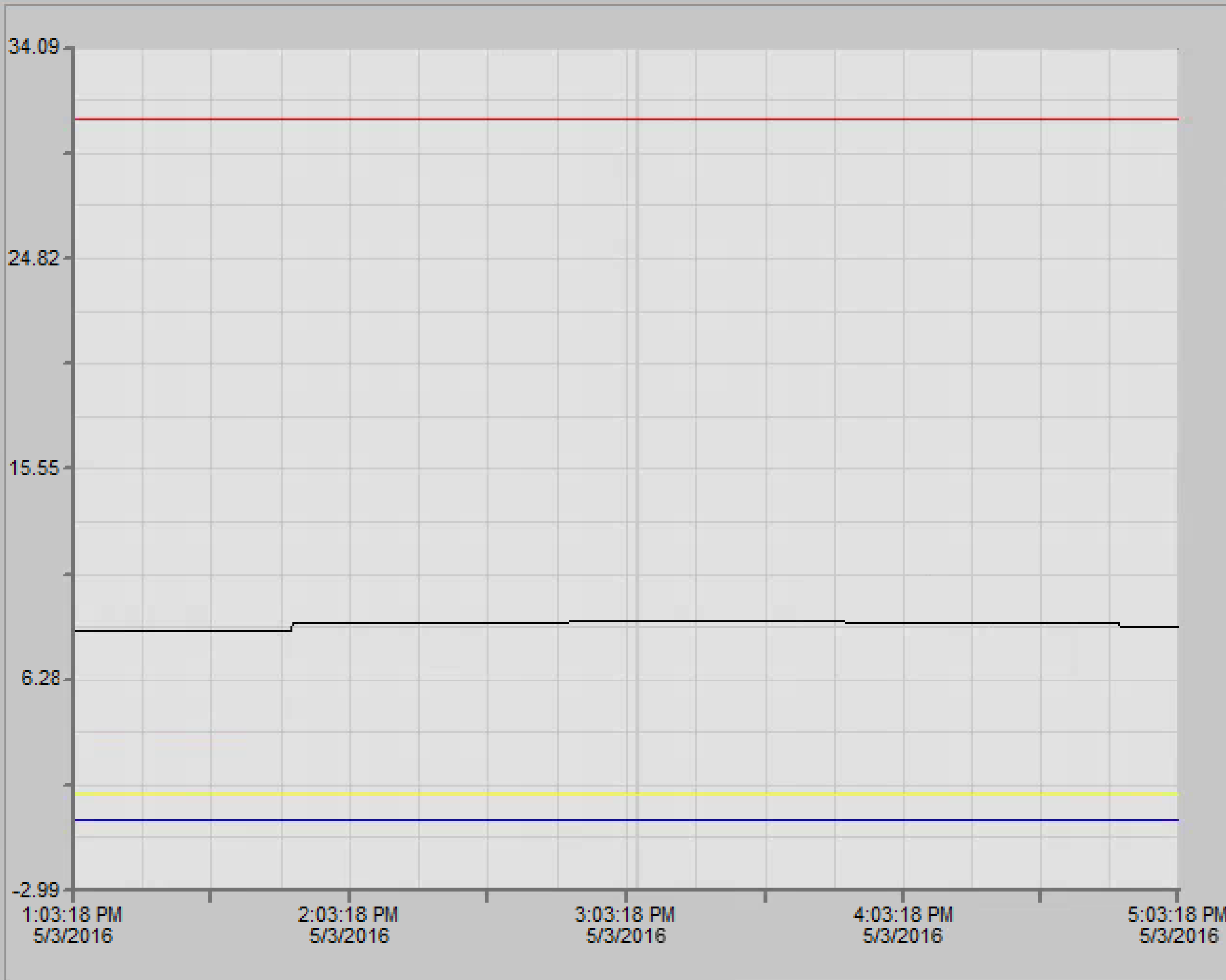
28607002
SSO-1066
LOWER MILL
CREEK
CSO-004
29403034
CENTRAL

METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI

CURRENT USER: REESE JOHNSON

5/3/2016
5:03:28 PM

MSDGC > MILL CREEK > LOWER MILL CREEK > SSO-1066



LAST POLL: 5/3/2016 4:45:00 PM

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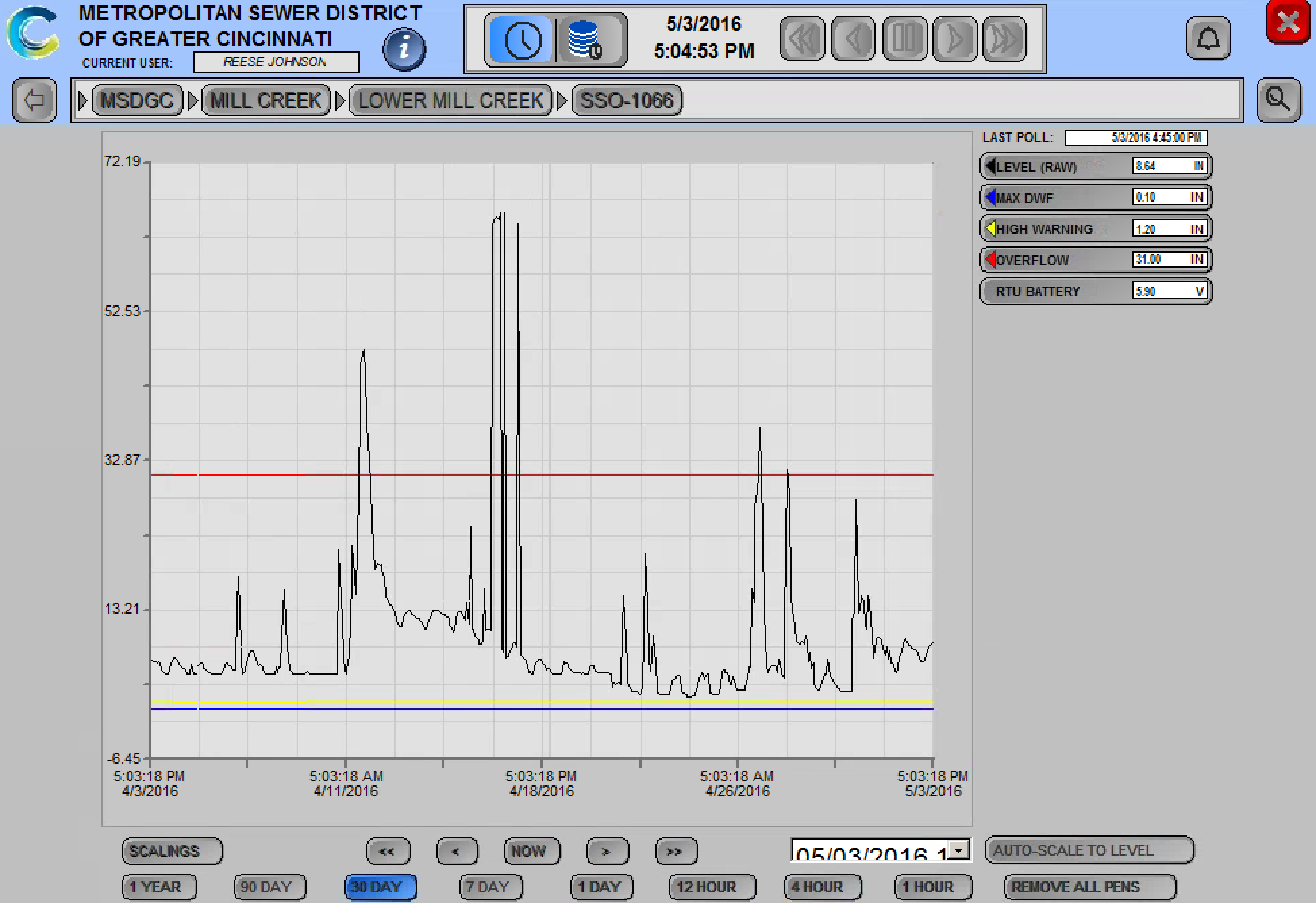
HIGH WARNING	1.20	IN
OVERFLOW	31.00	IN
RTU BATTERY	5.90	V

SCALINGS | << | < | NOW | > | >> | 05/03/2016 1 | AUTO-SCALE TO LEVEL

1 YEAR | 90 DAY | 30 DAY | 7 DAY | 1 DAY | 12 HOUR | 4 HOUR | 1 HOUR | REMOVE ALL PENS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OF GREATER CINCINNATI
CURRENT USER:
REESE JOHNSON
5/3/2016
5:04:53 PM
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MILL CREEK
LOWER MILL CREEK
SSO-1066
LAST POLL:
5/3/2016 4:45:00 PM
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8.64
IN
MAX DWF
0.10
IN
HIGH WARNING
1.20
IN
OVERFLOW
31.00
IN
RTU BATTERY
5.90
V
72.19
52.53
32.87
13.21
-6.45
5:03:18 PM
4/3/2016
5:03:18 AM
4/11/2016
5:03:18 PM
4/18/2016
5:03:18 AM
4/26/2016
5:03:18 PM
5/3/2016
SCALINGS
<<
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NOW
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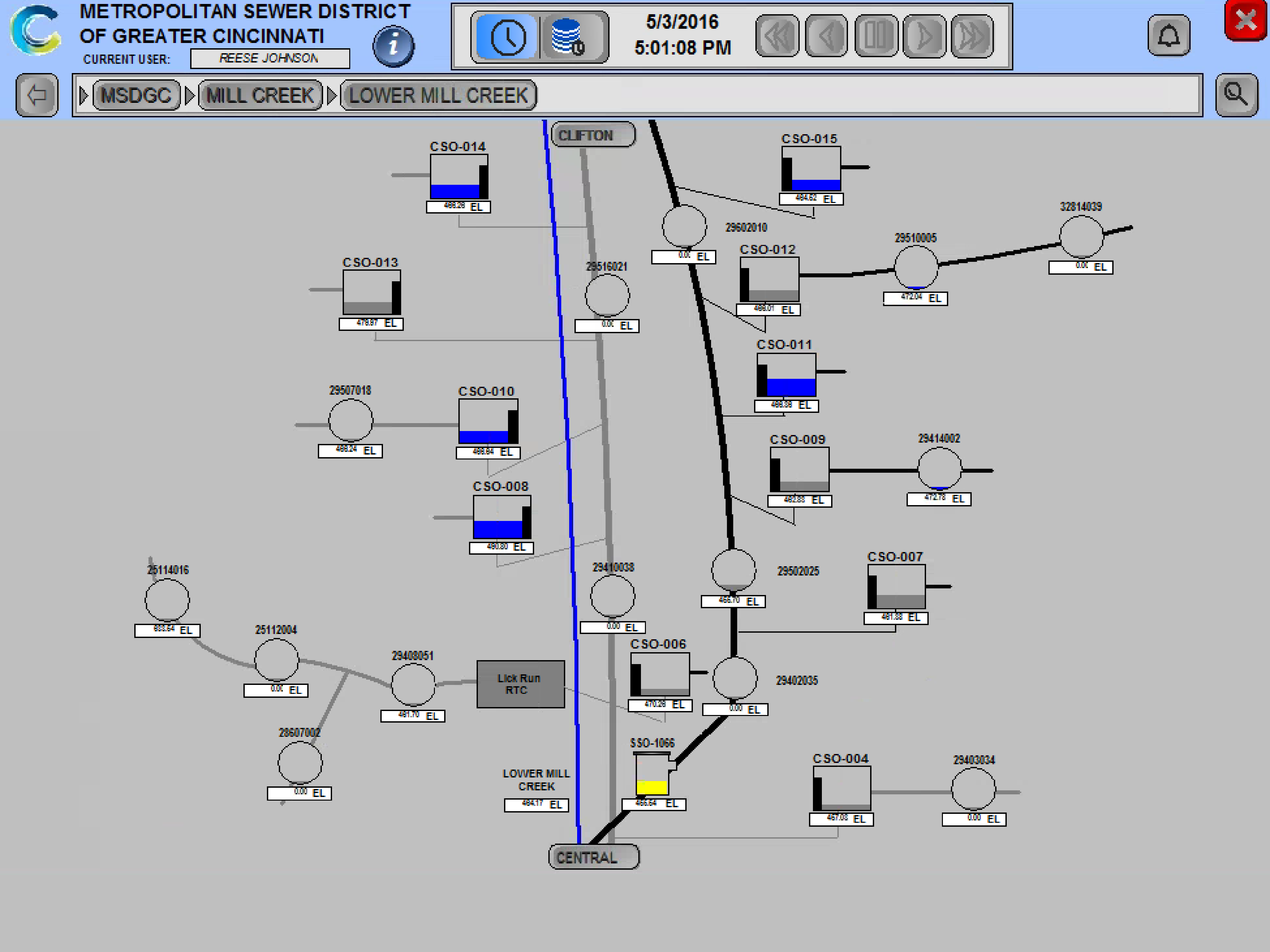
>>
05/03/2016 1
AUTO-SCALE TO LEVEL
1 YEAR
90 DAY
30 DAY
7 DAY
1 DAY
12 HOUR
4 HOUR
1 HOUR
REMOVE ALL PENS



METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
REESE JOHNSON
5/3/2016
5:01:08 PM
MSDGC
MILL CREEK
LOWER MILL CREEK
CLIFTON
CSO-014
CSO-015
32814039
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CSO-012
CSO-013
29516021
CSO-011
29507018
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CSO-009
29414002
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29408051
Lick Run
RTC
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SSO-1066
LOWER MILL
CREEK
CSO-004
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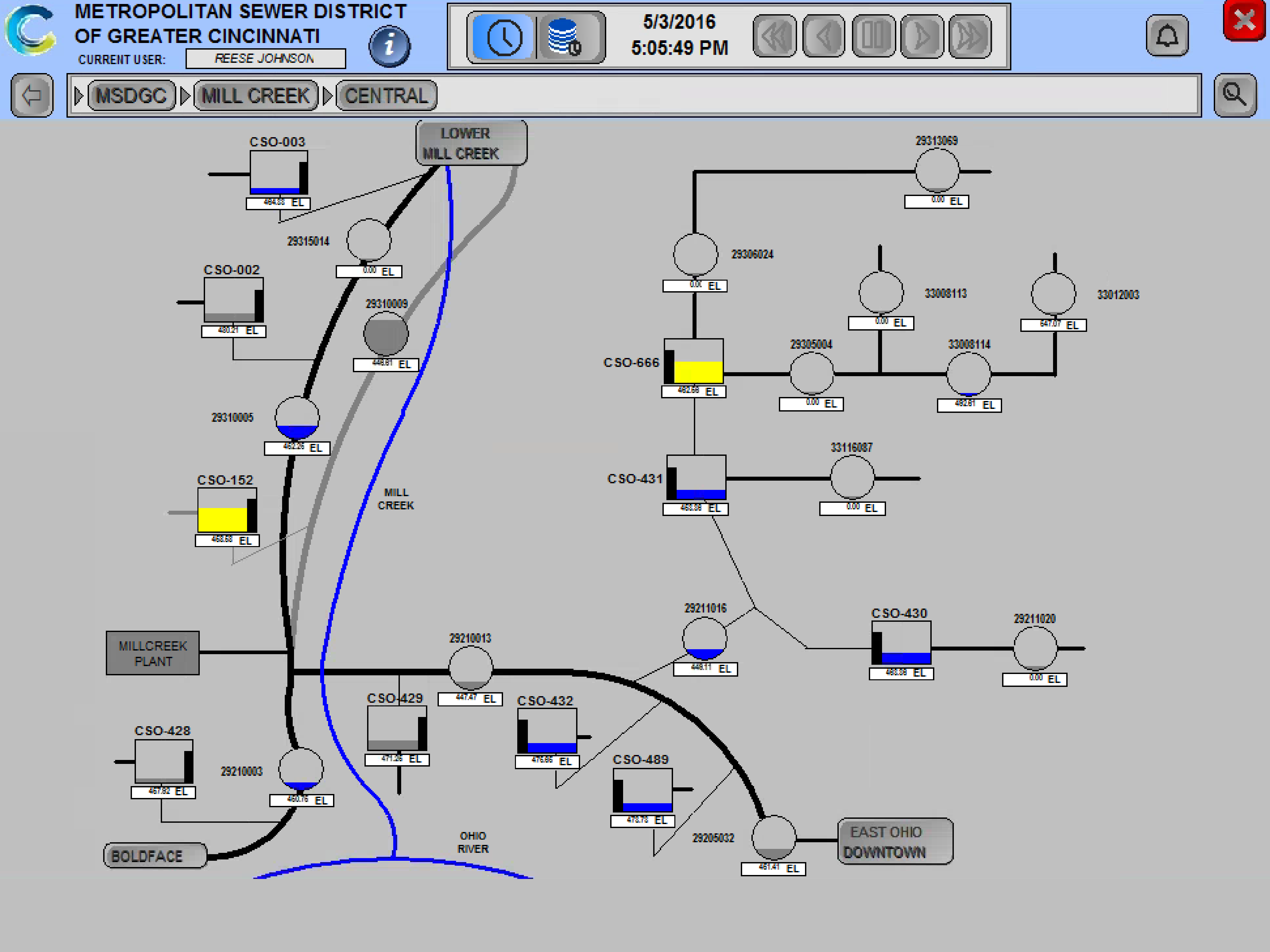
CENTRAL
EL



METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
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5/3/2016
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CENTRAL
LOWER MILL CREEK
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CSO-002
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MILL CREEK
MILLCREEK PLANT
CSO-428
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BOLDFACE
CSO-429
29210013
CSO-432
CSO-489
OHIO RIVER
29205032
EAST OHIO DOWNTOWN
29211016
CSO-430
29211020
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29306024
33008113
33012003
CSO-666
29305004
33008114
CSO-431
33116087
EL

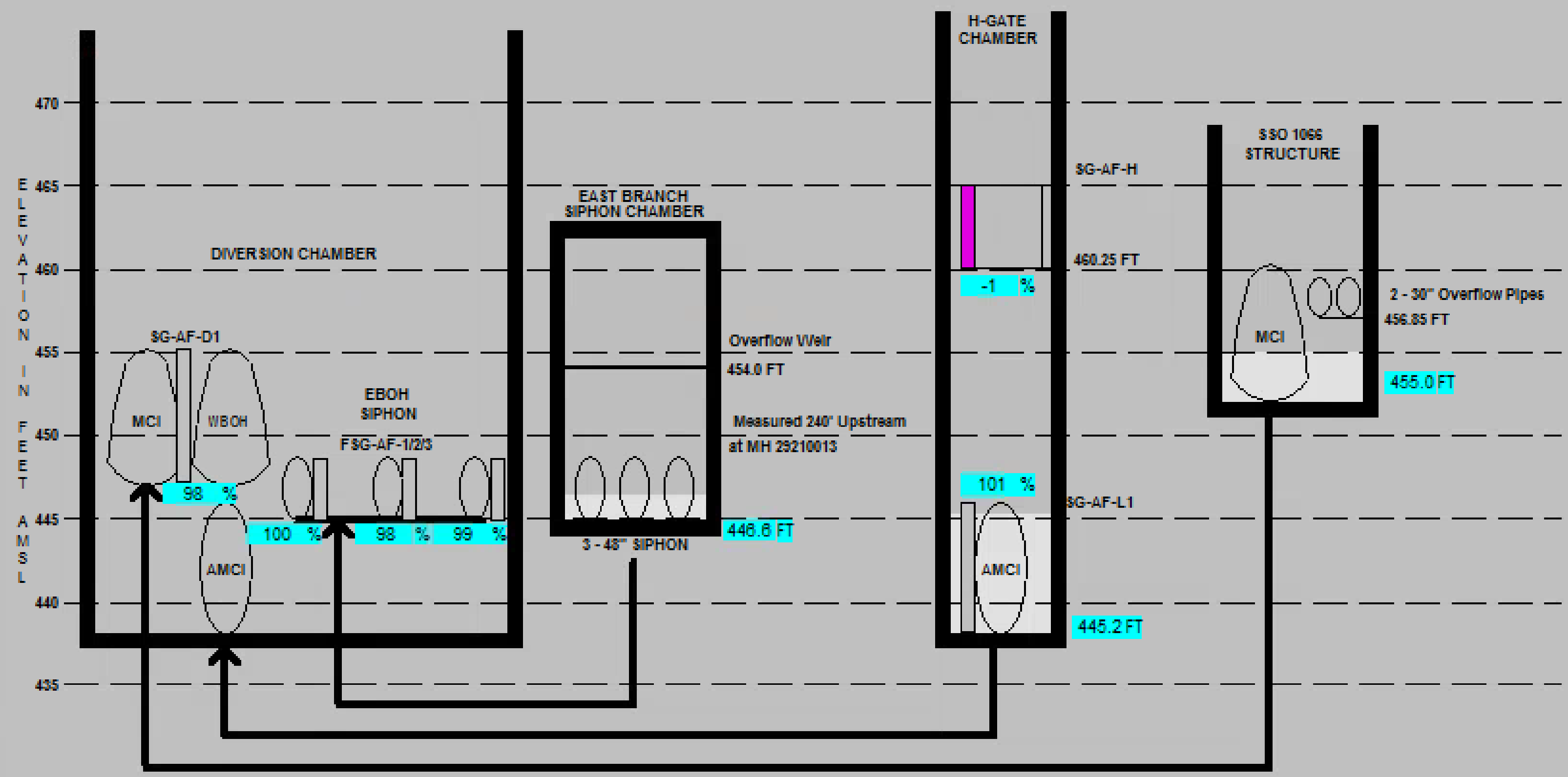
METROPOLITAN SEWER DISTRICT OF GREATER CINCINNATI

CURRENT USER: REESE JOHNSON

5/3/2016 5:07:26 PM

MSDGC > MILL CREEK > CENTRAL > WWTP > DIVERSION CHAMBER

NOTE: ONLY STRUCTURES ARE SHOWN IN VERTICAL SCALE MATCHING DEVICE LIMITS



INFLUENT FLOW PROJECTION

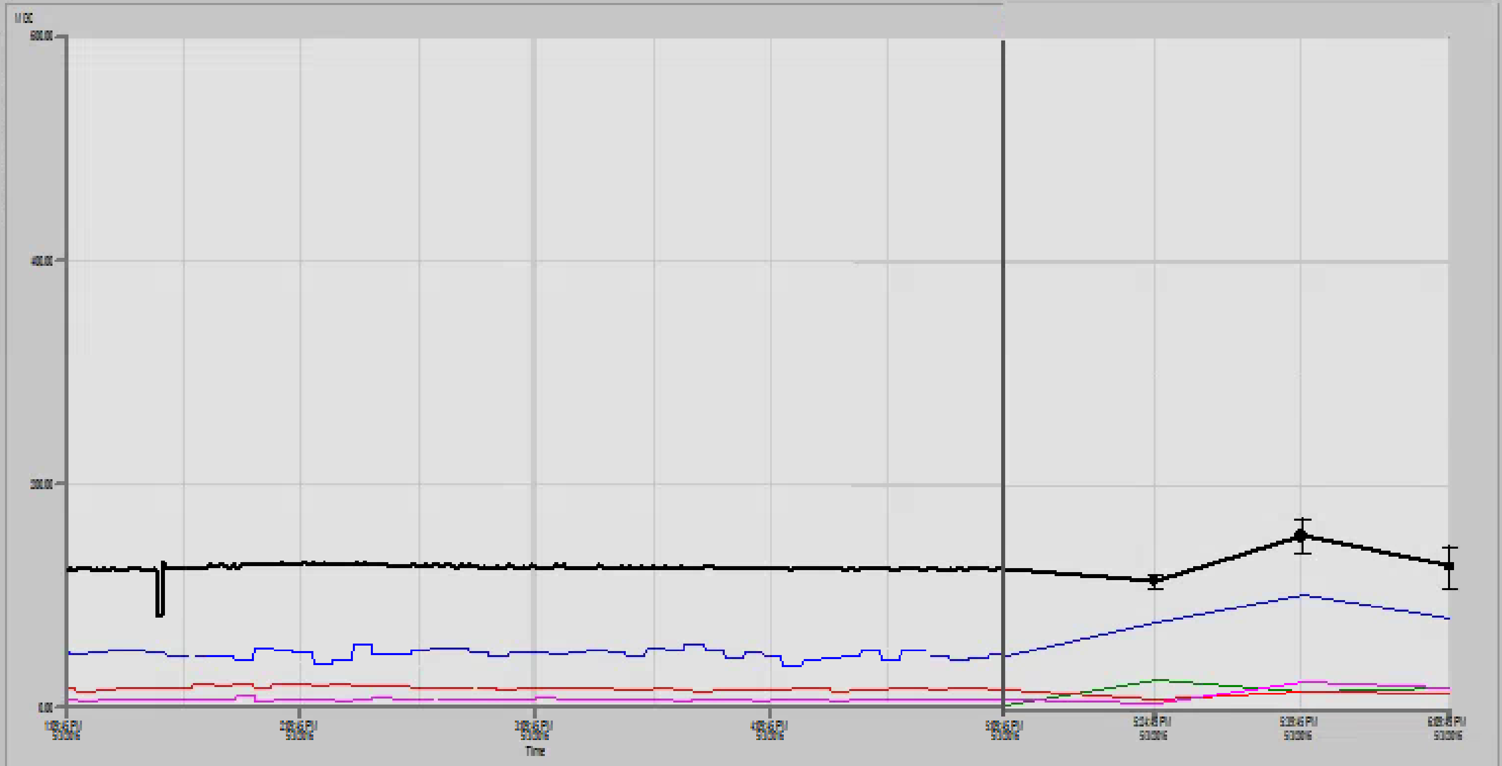
INFLUENT FLOW TREND

METROPOLITAN SEWER DISTRICT OF GREATER CINCINNATI

CURRENT USER: REESE JOHNSON

5/3/2016
5:09:50 PM

MSDGC > MILL CREEK > CENTRAL > WWTP > DIVERSION CHAMBER > FLOW PROJECTIONS



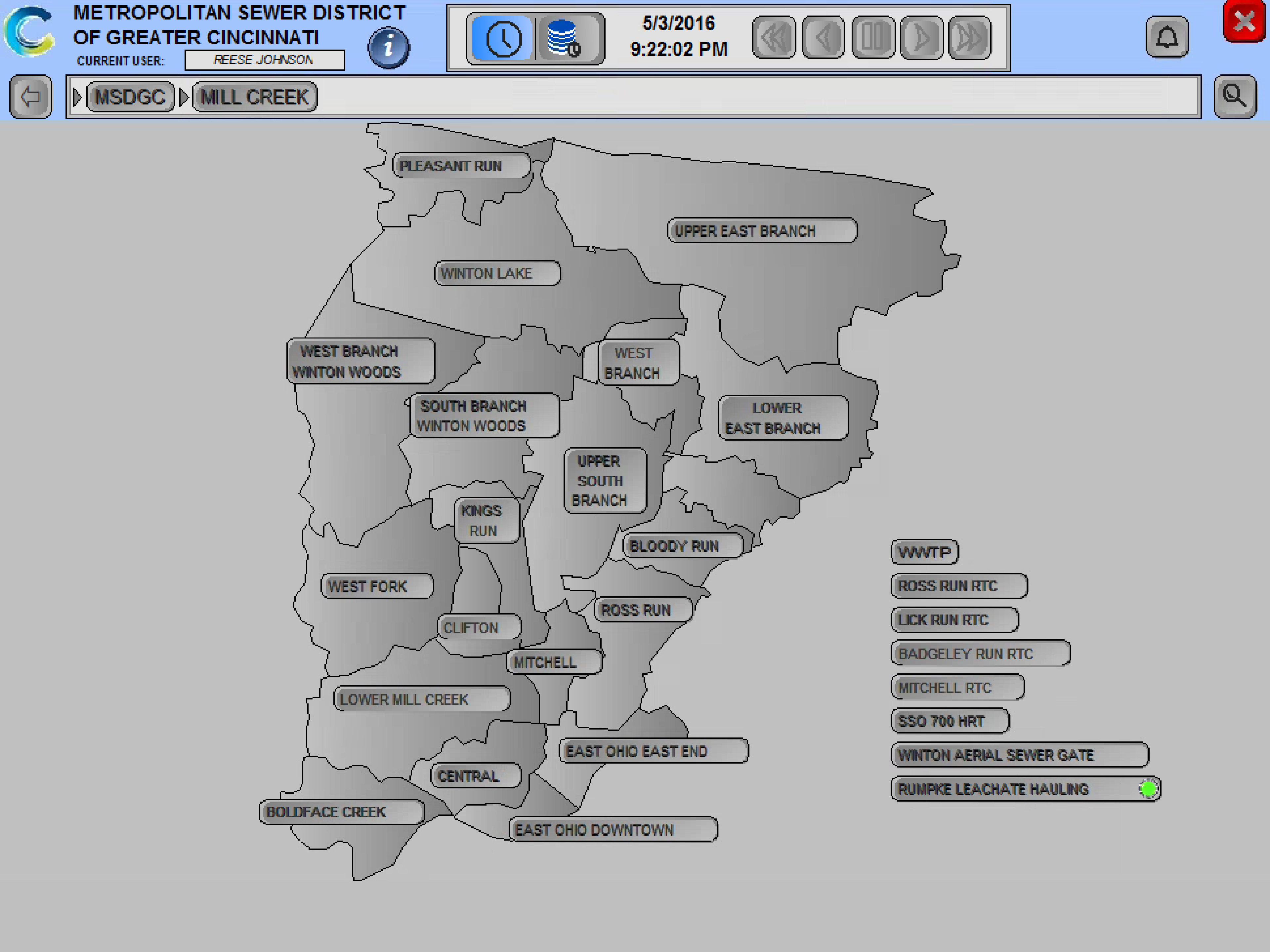
LEGEND:

Enable:	Color:	Description:	7 Day Avg. (MGD):	△ % from Avg.:
☑	Black	Mill Creek WTP Influent (Total)	????	????
☑	Blue	Auxiliary Mill Creek Interceptor (AMCI)	????	????
☑	Green	Mill Creek Interceptor (MCI)	????	????
☑	Red	East Branch Ohio River Interceptor (EBOH)	????	????
☑	Magenta	West Branch Ohio River Interceptor (WBOH)	????	????

Last Updated	NOW	Last Updated	< 30 min	Last Updated	30 min	Last Updated	60 min
	124.00		114		166		127
-5	47.78	-3	78	-3	102	-3	78
0	2.18	0	28	-1	16	-3	18
0	16.10	-2	7	-2	14	-2	13
0	7.88	-3	6	-4	26	-4	17

1 HOUR | 1 DAY | 1 WEEK | 1 MONTH | CURRENT

1 HOUR
FLOW PROJECTION


METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
REESE JOHNSON
5/3/2016
9:22:02 PM
MSDGC
MILL CREEK
PLEASANT RUN
UPPER EAST BRANCH
WINTON LAKE
WEST BRANCH WINTON WOODS
WEST BRANCH
SOUTH BRANCH WINTON WOODS
LOWER EAST BRANCH
UPPER SOUTH BRANCH
KINGS RUN
BLOODY RUN
WEST FORK
ROSS RUN
CLIFTON
MITCHELL
LOWER MILL CREEK
EAST OHIO EAST END
CENTRAL
BOLDFACE CREEK
EAST OHIO DOWNTOWN
WWTP
ROSS RUN RTC
LICK RUN RTC
BADGELEY RUN RTC
MITCHELL RTC
SSO 700 HRT
WINTON AERIAL SEWER GATE
RUMPKE LEACHATE HAULING

METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI

CURRENT USER: REESE JOHNSON

5/3/2016
5:14:43 PM

MSDGC > MILL CREEK > LOWER MILL CREEK > RUMPKE LEACHATE HAULING

Readiness: YES

TREND

PLC Heartbeat 6325

Mill Creek Interceptor Gate Position: 97.7 %

SSO-1066 Level: 8.6 IN

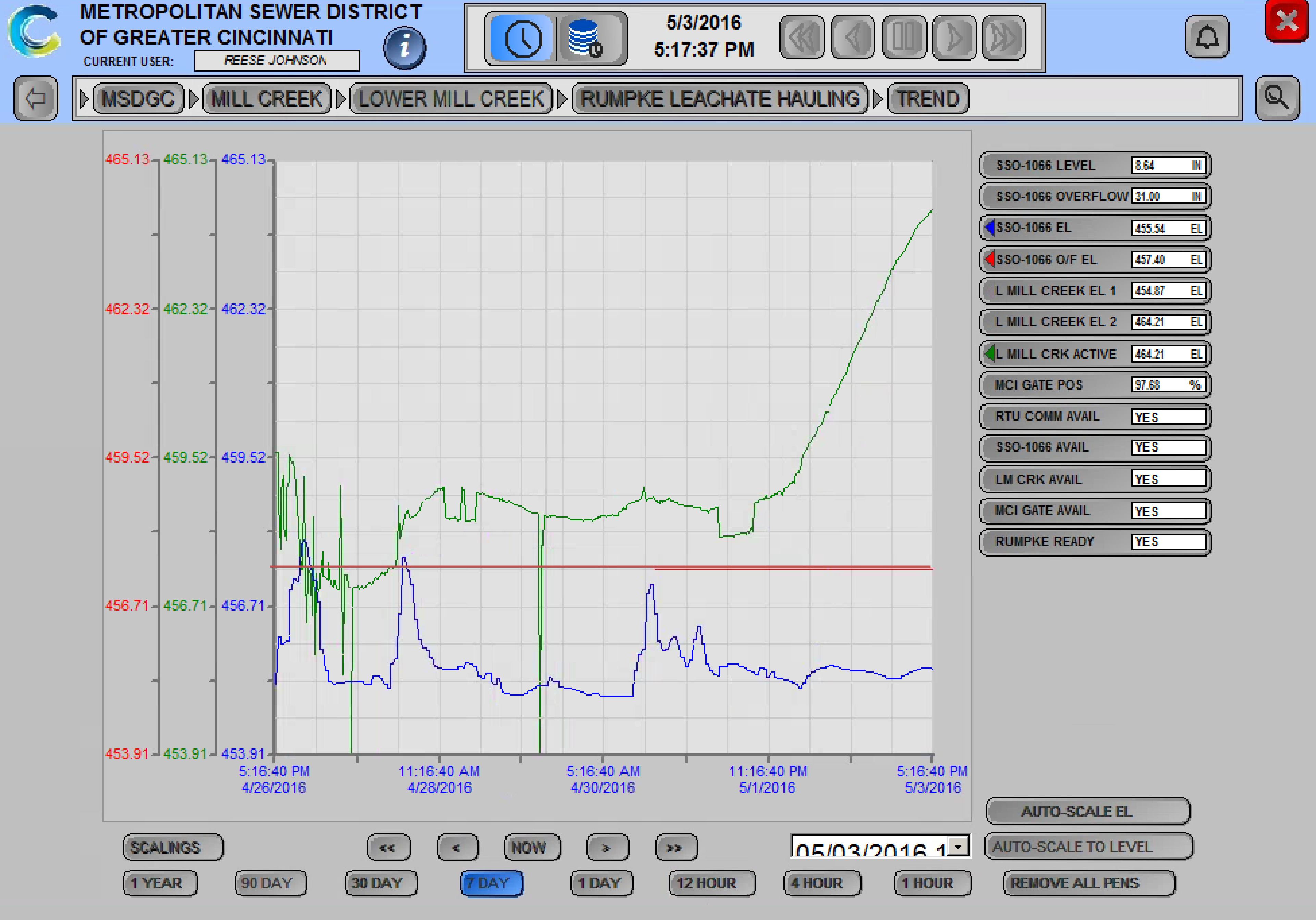
SSO-1066 Elevation: 455.5 EL

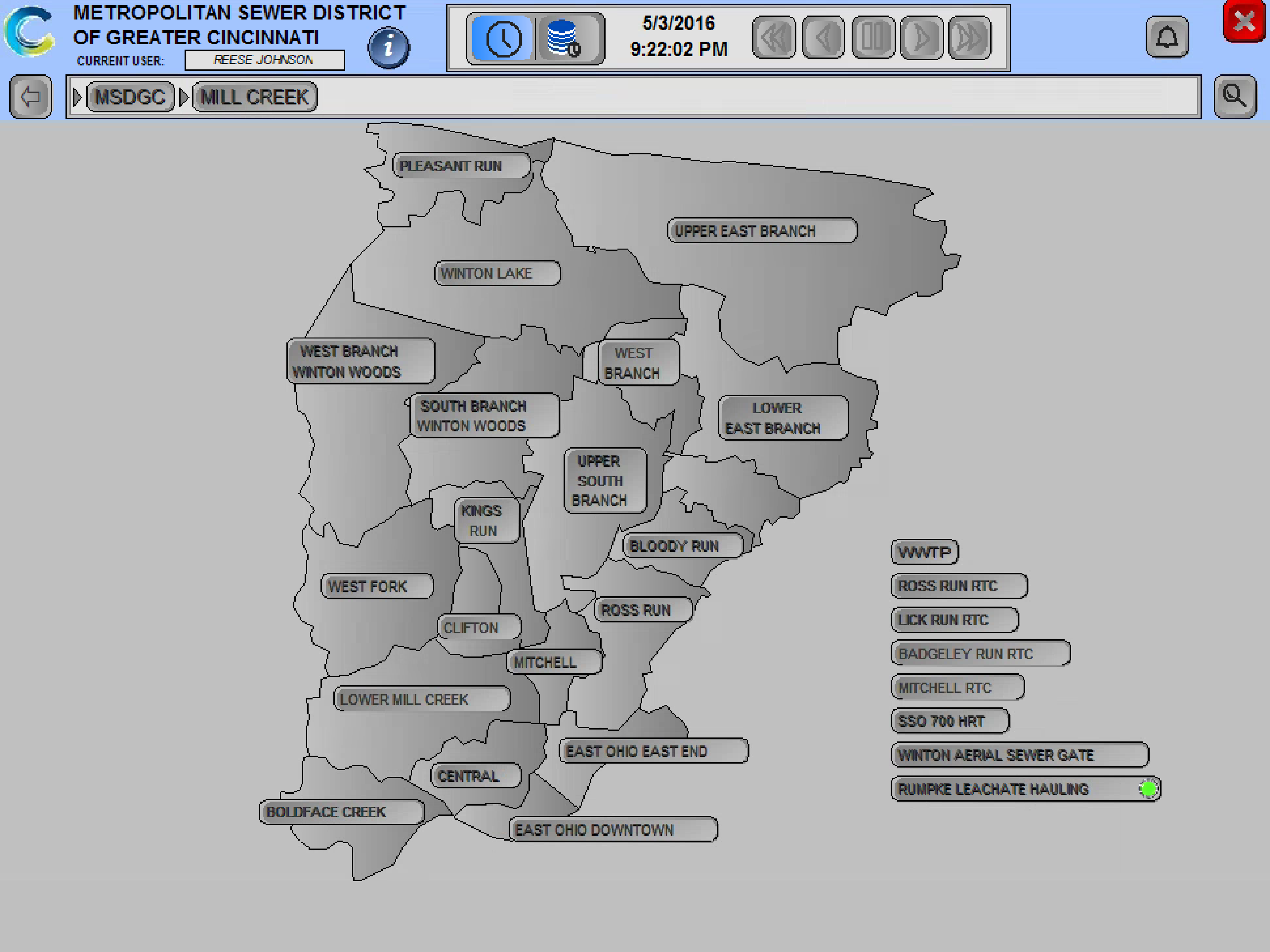
Lower Mill Creek Elevation 1: 454.9 EL FAIL 5/3/2016 4:40:00 PM

Lower Mill Creek Elevation 2: 464.2 EL

Leachate Hauling Indicator: HAUL LEACHATE TO ST. BERNARD FACILITY

Leachate Hauling Indicator Control: Auto | Man


METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER: REESE JOHNSON
5/3/2016
5:17:37 PM
MSDGC
MILL CREEK
LOWER MILL CREEK
RUMPKE LEACHATE HAULING
TREND
465.13 465.13 465.13
462.32 462.32 462.32
459.52 459.52 459.52
456.71 456.71 456.71
453.91 453.91 453.91
5:16:40 PM 4/26/2016
11:16:40 AM 4/28/2016
5:16:40 AM 4/30/2016
11:16:40 PM 5/1/2016
5:16:40 PM 5/3/2016
SSO-1066 LEVEL 8.64 IN
SSO-1066 OVERFLOW 31.00 IN
SSO-1066 EL 455.54 EL
SSO-1066 O/F EL 457.40 EL
L MILL CREEK EL 1 454.87 EL
L MILL CREEK EL 2 464.21 EL
L MILL CRK ACTIVE 464.21 EL
MCI GATE POS 97.68 %
RTU COMM AVAIL YES
SSO-1066 AVAIL YES
LM CRK AVAIL YES
MCI GATE AVAIL YES
RUMPKE READY YES
AUTO-SCALE EL
AUTO-SCALE TO LEVEL
SCALINGS
<<
<
NOW
>
>>
05/03/2016 1
1 YEAR
90 DAY
30 DAY
7 DAY
1 DAY
12 HOUR
4 HOUR
1 HOUR
REMOVE ALL PENS



METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
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5/3/2016
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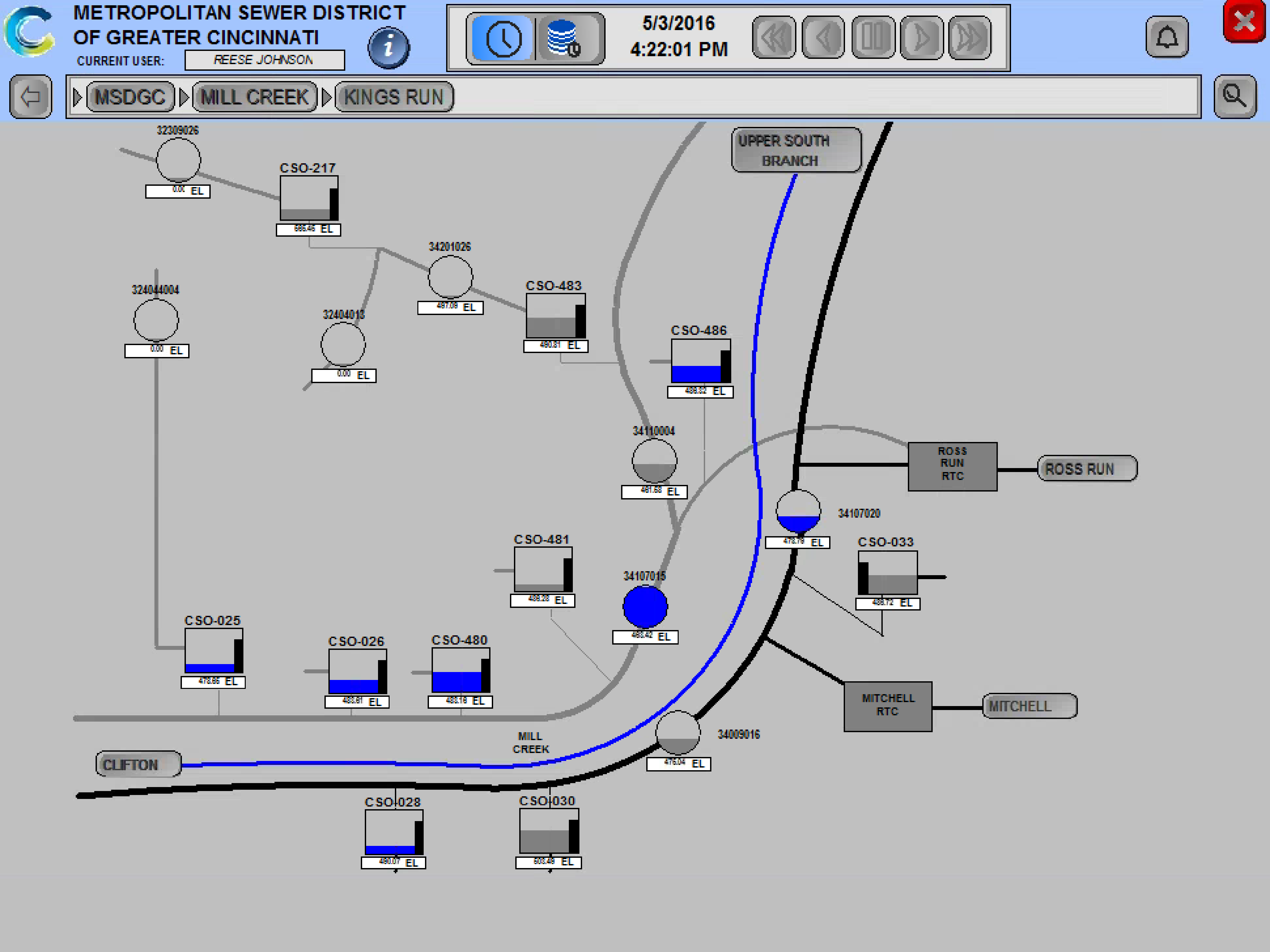
MSDGC
MILL CREEK
PLEASANT RUN
UPPER EAST BRANCH
WINTON LAKE
WEST BRANCH WINTON WOODS
WEST BRANCH
SOUTH BRANCH WINTON WOODS
LOWER EAST BRANCH
UPPER SOUTH BRANCH
KINGS RUN
BLOODY RUN
WEST FORK
ROSS RUN
CLIFTON
MITCHELL
LOWER MILL CREEK
EAST OHIO EAST END
CENTRAL
BOLDFACE CREEK
EAST OHIO DOWNTOWN
WWTP
ROSS RUN RTC
LICK RUN RTC
BADGELEY RUN RTC
MITCHELL RTC
SSO 700 HRT
WINTON AERIAL SEWER GATE
RUMPKE LEACHATE HAULING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OF GREATER CINCINNATI
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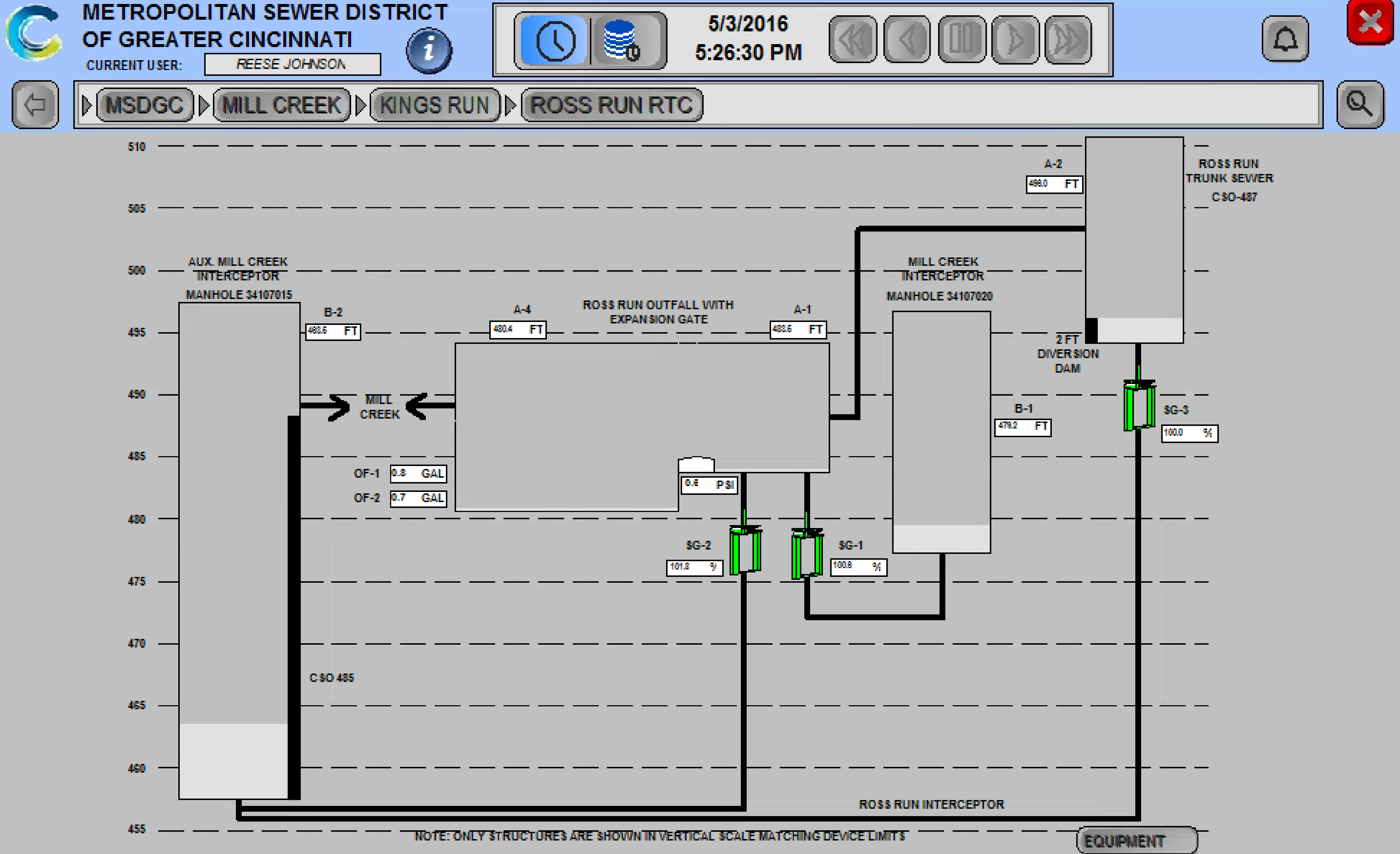
MSDGC
MILL CREEK
KINGS RUN
32309026
CSO-217
34201026
324044004
32404013
CSO-483
CSO-486
UPPER SOUTH BRANCH
34110004
ROSS RUN RTC
ROSS RUN
34107020
CSO-481
34107015
CSO-033
CSO-025
CSO-026
CSO-480
MITCHELL RTC
MITCHELL
34009016
MILL CREEK
CLIFTON
CSO-028
CSO-030
EL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OF GREATER CINCINNATI
CURRENT USER:
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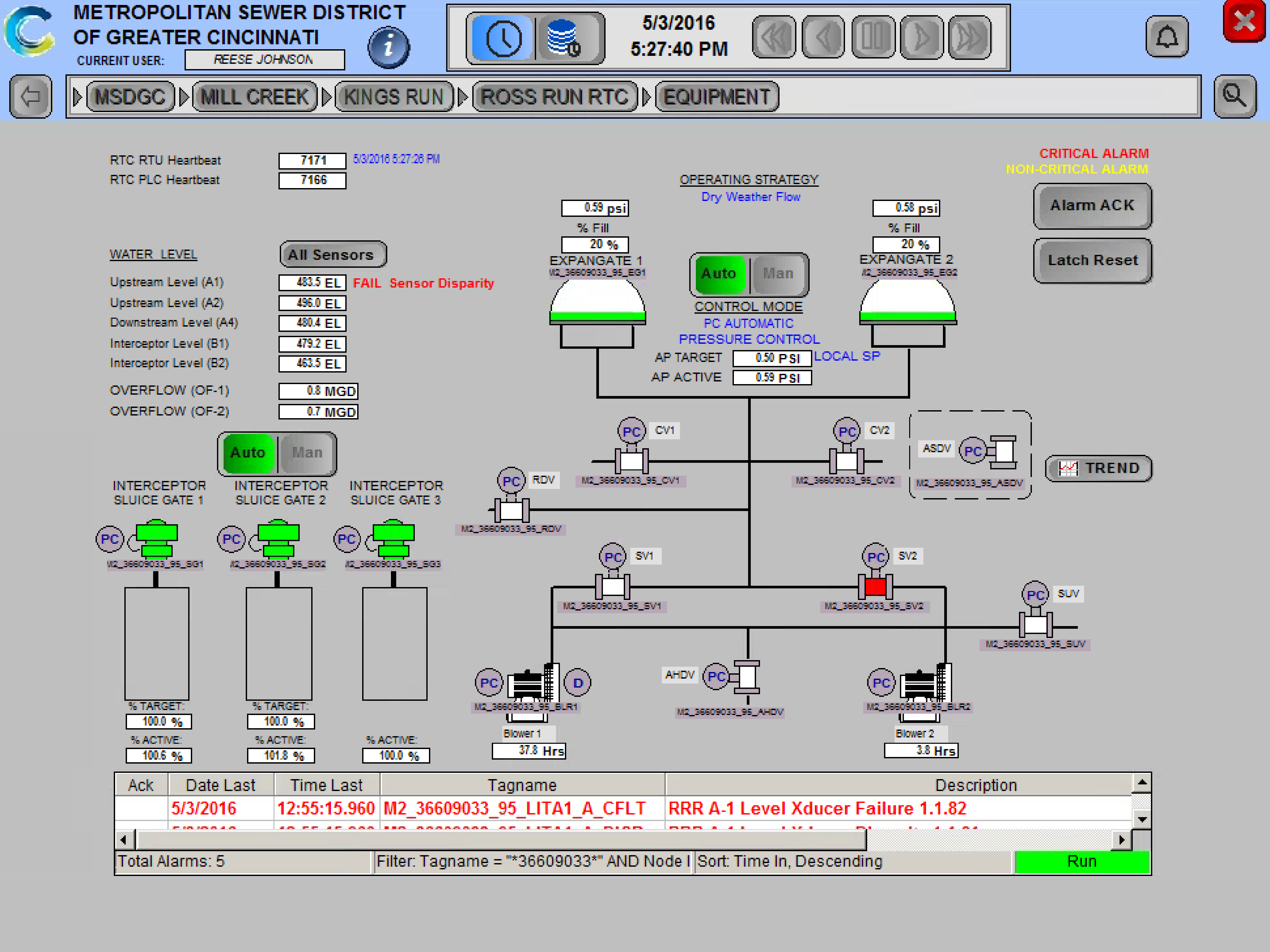
5/3/2016
5:26:30 PM
MSDGC
MILL CREEK
KINGS RUN
ROSS RUN RTC
510
505
500
495
490
485
480
475
470
465
460
455
AUX. MILL CREEK
INTERCEPTOR
MANHOLE 34107015
B-2
FT
A-4
480.4 FT
ROSS RUN OUTFALL WITH
EXPANSION GATE
A-1
FT
A-2
FT
ROSS RUN
TRUNK SEWER
CSO-487
MILL CREEK
INTERCEPTOR
MANHOLE 34107020
2 FT
DIVERSION
DAM
MILL
CREEK
OF-1
GAL
OF-2
GAL
PSI
B-1
478.2 FT
SG-3
100.0 %
SG-2
101.3 %
SG-1
100.8 %
CSO 485
ROSS RUN INTERCEPTOR
NOTE: ONLY STRUCTURES ARE SHOWN IN VERTICAL SCALE MATCHING DEVICE LIMITS
EQUIPMENT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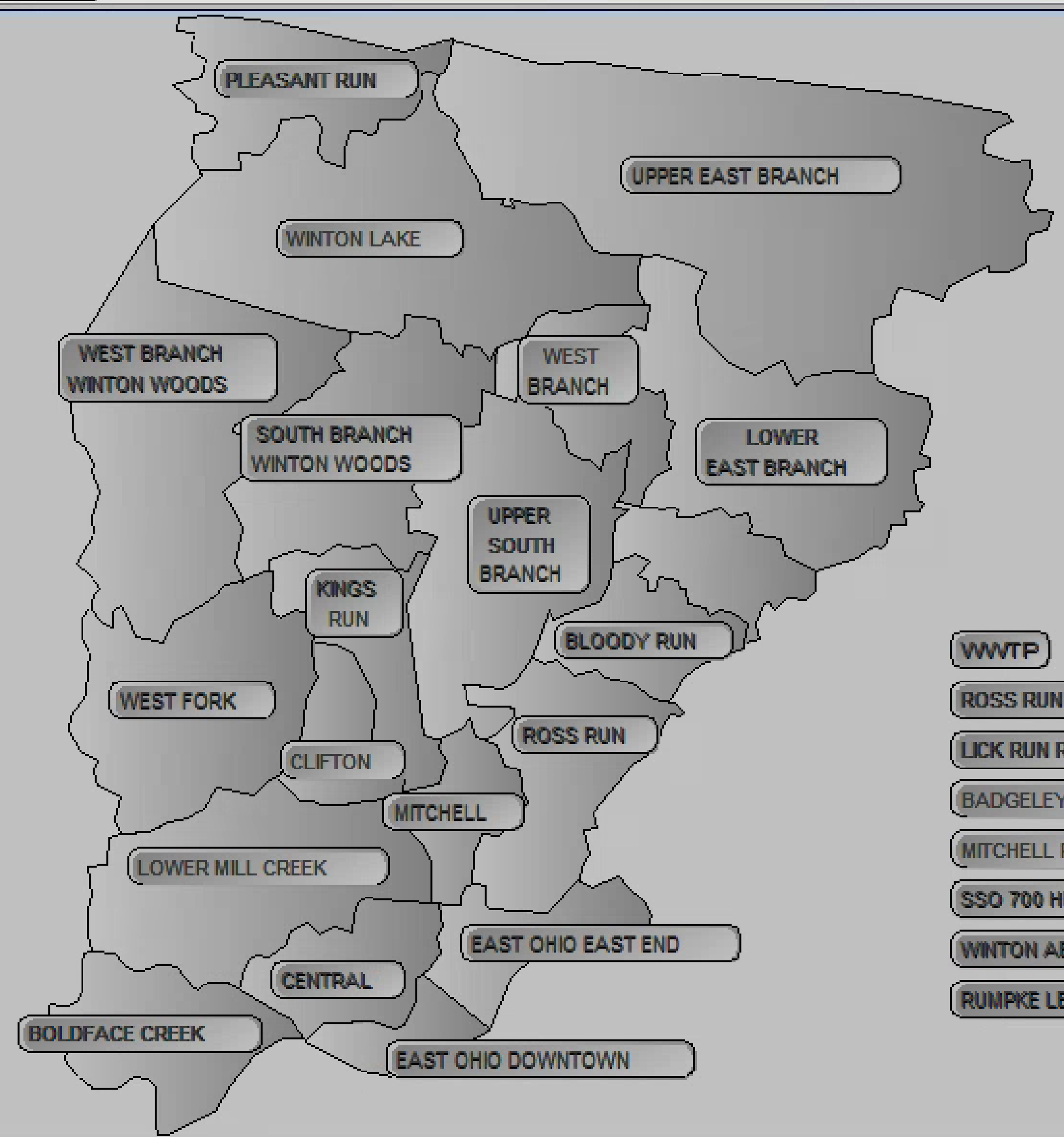
CURRENT USER: REESE JOHNSON
5/3/2016
5:27:40 PM
MSDGC
MILL CREEK
KINGS RUN
ROSS RUN RTC
EQUIPMENT
RTC RTU Heartbeat 7171 5/3/2016 5:27:26 PM
RTC PLC Heartbeat 7166
CRITICAL ALARM
NON-CRITICAL ALARM
Alarm ACK
Latch Reset
OPERATING STRATEGY
Dry Weather Flow
0.59 psi
% Fill
20 %
EXPANGATE 1
M2_36609033_95_EG1
0.58 psi
% Fill
20 %
EXPANGATE 2
M2_36609033_95_EG2
Auto
Man
CONTROL MODE
PC AUTOMATIC
PRESSURE CONTROL
AP TARGET 0.50 PSI LOCAL SP
AP ACTIVE 0.59 PSI
WATER LEVEL
All Sensors
Upstream Level (A1) 483.5 EL FAIL Sensor Disparity
Upstream Level (A2) 496.0 EL
Downstream Level (A4) 480.4 EL
Interceptor Level (B1) 479.2 EL
Interceptor Level (B2) 463.5 EL
OVERFLOW (OF-1) 0.8 MGD
OVERFLOW (OF-2) 0.7 MGD
Auto
Man
INTERCEPTOR SLUICE GATE 1
INTERCEPTOR SLUICE GATE 2
INTERCEPTOR SLUICE GATE 3
M2_36609033_95_SG1
M2_36609033_95_SG2
M2_36609033_95_SG3
% TARGET: 100.0 %
% ACTIVE: 100.6 %
% TARGET: 100.0 %
% ACTIVE: 101.8 %
% ACTIVE: 100.0 %
CV1
M2_36609033_95_CV1
CV2
M2_36609033_95_CV2
ASDV
M2_36609033_95_ASDV
TREND
RDV
M2_36609033_95_RDV
SV1
M2_36609033_95_SV1
SV2
M2_36609033_95_SV2
SUV
M2_36609033_95_SUV
AHDV
M2_36609033_95_AHDV
M2_36609033_95_BLR1
Blower 1
37.8 Hrs
M2_36609033_95_BLR2
Blower 2
3.8 Hrs
Ack | Date Last | Time Last | Tagname | Description
5/3/2016 | 12:55:15.960 | M2_36609033_95_LITA1_A_CFLT | RRR A-1 Level Xducer Failure 1.1.82
Total Alarms: 5
Filter: Tagname = "*36609033*" AND Node I
Sort: Time In, Descending
Run

METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI

CURRENT USER: REESE JOHNSON

5/3/2016
9:22:02 PM

MSDGC > MILL CREEK



WWTP

ROSS RUN RTC

LICK RUN RTC

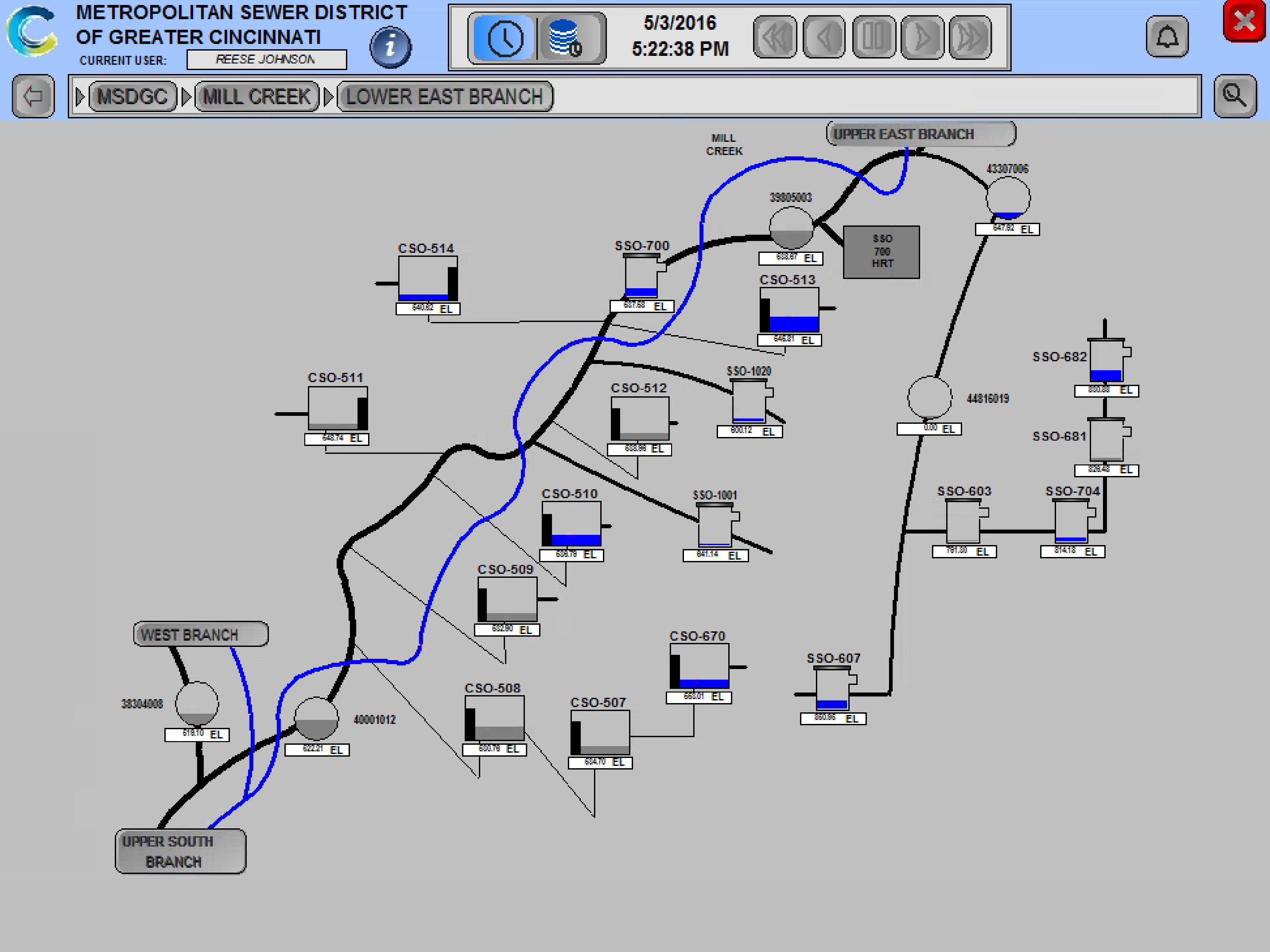
BADGELEY RUN RTC

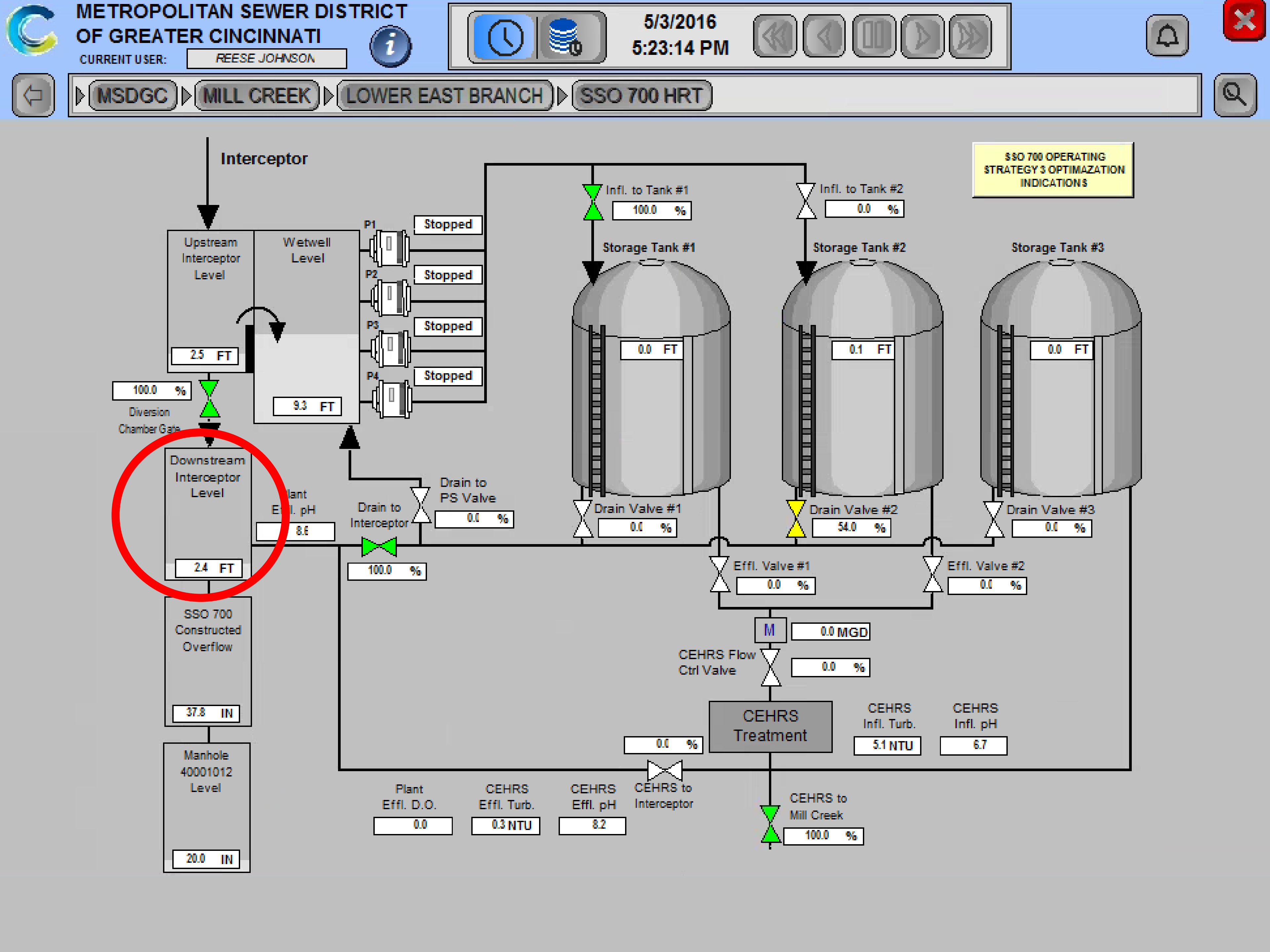
MITCHELL RTC

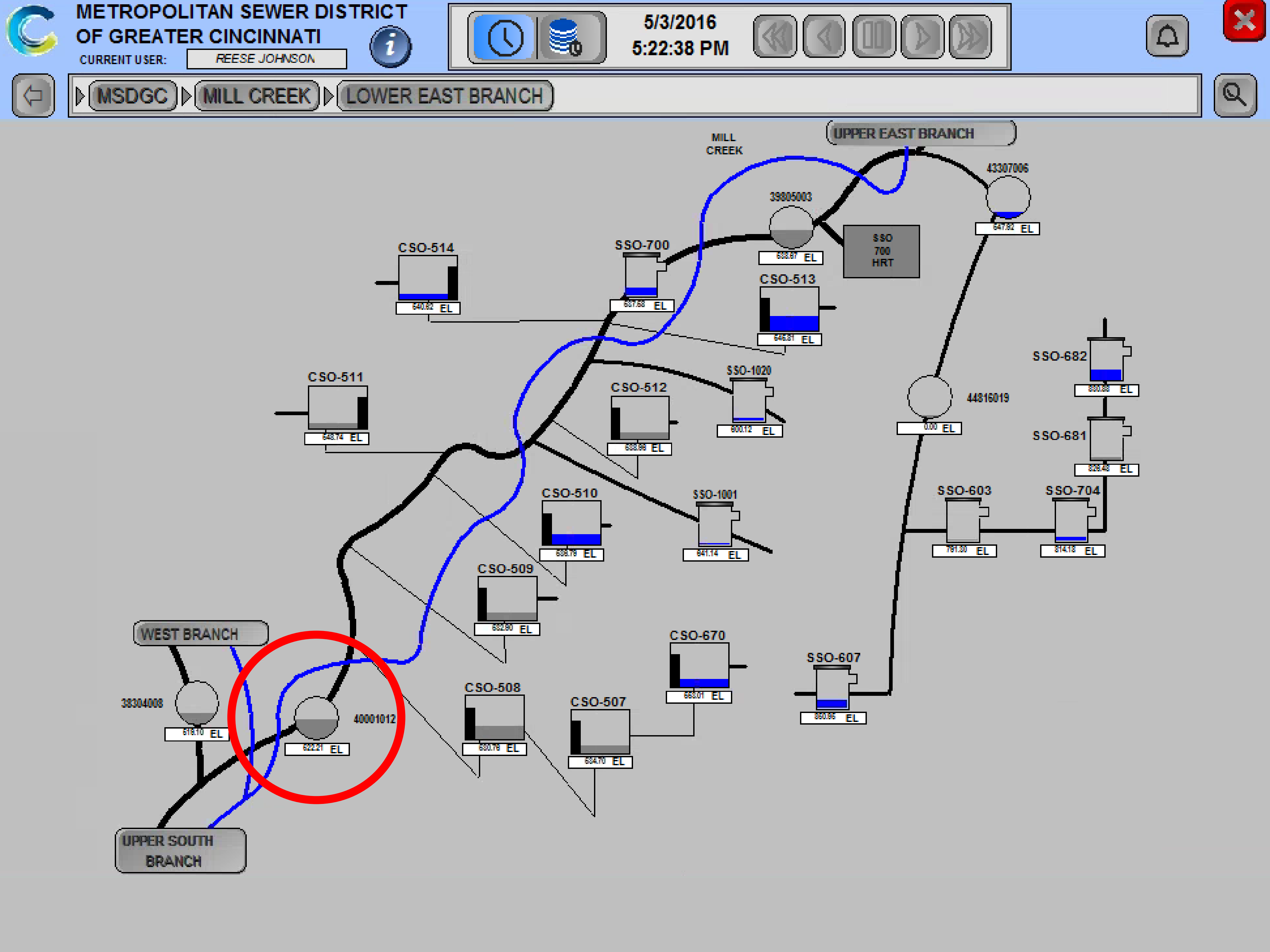
SSO 700 HRT

WINTON AERIAL SEWER GATE

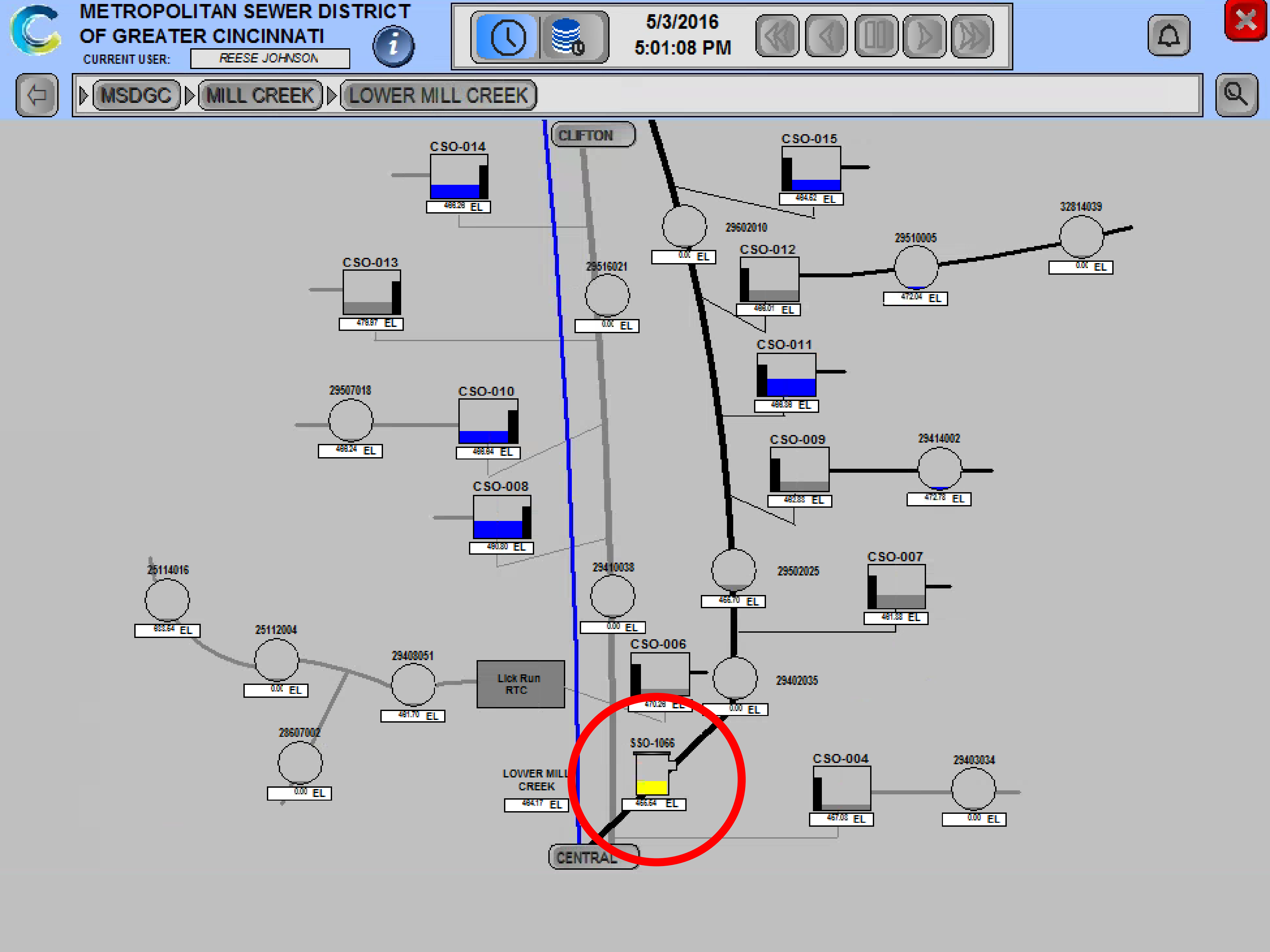
RUMPKE LEACHATE HAULING


METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
REESE JOHNSON
5/3/2016
5:22:38 PM
MSDGC
MILL CREEK
LOWER EAST BRANCH
UPPER EAST BRANCH
MILL CREEK
43307006
39805003
SSO 700 HRT
CSO-514
SSO-700
CSO-513
SSO-682
CSO-511
SSO-1020
CSO-512
44816019
SSO-681
CSO-510
SSO-1001
SSO-603
SSO-704
CSO-509
WEST BRANCH
CSO-670
SSO-607
CSO-508
CSO-507
38304008
40001012
UPPER SOUTH BRANCH
EL


METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
REESE JOHNSON
5/3/2016
5:23:14 PM
MSDGC
MILL CREEK
LOWER EAST BRANCH
SSO 700 HRT
Interceptor
SSO 700 OPERATING STRATEGY 3 OPTIMAZATION INDICATIONS
Infl. to Tank #1
100.0 %
Infl. to Tank #2
0.0 %
Storage Tank #1
Storage Tank #2
Storage Tank #3
Upstream Interceptor Level
2.5 FT
Wetwell Level
9.3 FT
P1
Stopped
P2
Stopped
P3
Stopped
P4
Stopped
0.0 FT
0.1 FT
0.0 FT
100.0 %
Diversion Chamber Gate
Downstream Interceptor Level
2.4 FT
Plant Effl. pH
Drain to Interceptor
100.0 %
Drain to PS Valve
0.0 %
Drain Valve #1
0.0 %
Drain Valve #2
54.0 %
Drain Valve #3
0.0 %
Effl. Valve #1
0.0 %
Effl. Valve #2
0.0 %
M
0.0 MGD
CEHRS Flow Ctrl Valve
0.0 %
SSO 700 Constructed Overflow
37.8 IN
CEHRS Treatment
CEHRS Infl. Turb.
5.1 NTU
CEHRS Infl. pH
6.7
0.0 %
Manhole 40001012 Level
20.0 IN
Plant Effl. D.O.
0.0
CEHRS Effl. Turb.
0.3 NTU
CEHRS Effl. pH
8.2
CEHRS to Interceptor
CEHRS to Mill Creek
100.0 %



METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
REESE JOHNSON
5/3/2016
5:22:38 PM
MSDGC
MILL CREEK
LOWER EAST BRANCH
UPPER EAST BRANCH
MILL
CREEK
39805003
43307006
SSO
700
HRT
CSO-514
SSO-700
CSO-513
CSO-511
CSO-512
SSO-1020
44816019
SSO-682
SSO-681
CSO-510
SSO-1001
SSO-603
SSO-704
CSO-509
WEST BRANCH
CSO-670
SSO-607
38304008
40001012
CSO-508
CSO-507
UPPER SOUTH
BRANCH

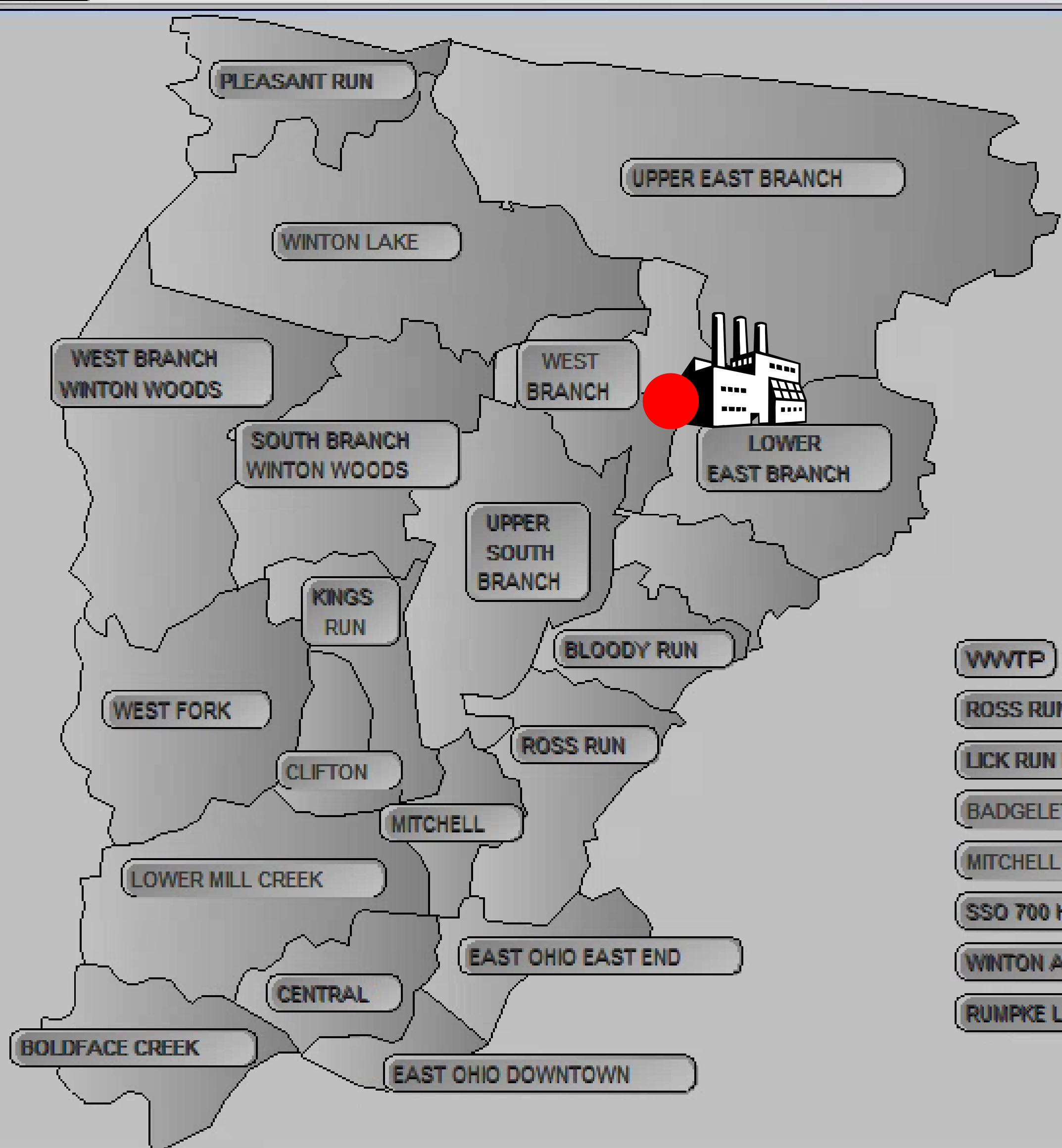

METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
REESE JOHNSON
5/3/2016
5:01:08 PM
MSDGC
MILL CREEK
LOWER MILL CREEK
CLIFTON
CSO-014
CSO-015
29602010
32814039
CSO-013
29516021
CSO-012
29510005
CSO-011
29507018
CSO-010
CSO-009
29414002
CSO-008
25114016
29410038
29502025
CSO-007
25112004
29408051
Lick Run
RTC
CSO-006
29402035
28607002
SSO-1066
LOWER MILL
CREEK
CSO-004
29403034
CENTRAL

METROPOLITAN SEWER DISTRICT OF GREATER CINCINNATI

CURRENT USER: REESE JOHNSON

5/3/2016 9:22:02 PM

MSDGC > MILL CREEK



WWTP

ROSS RUN RTC

LICK RUN RTC

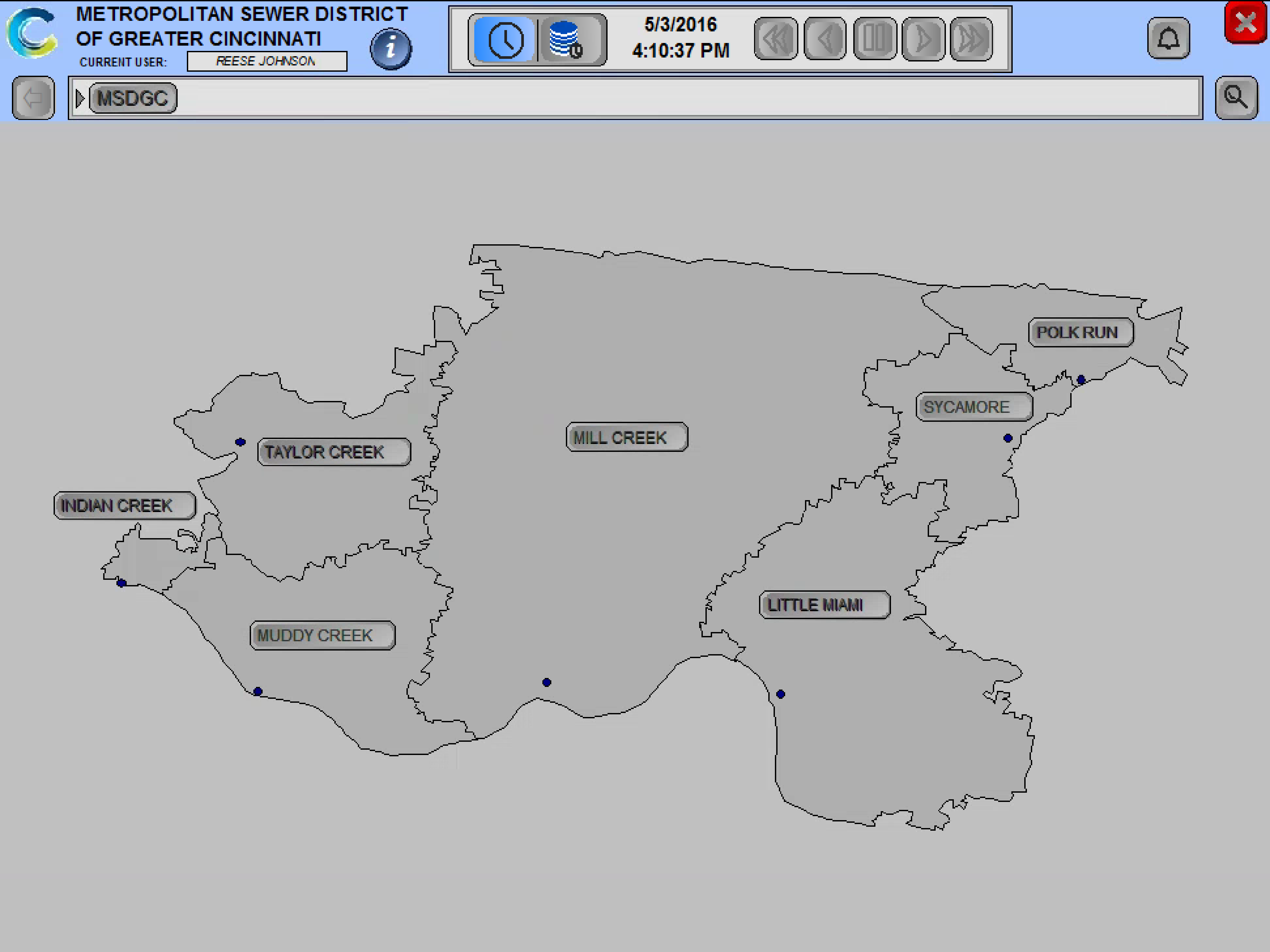
BADGELEY RUN RTC

MITCHELL RTC

SSO 700 HRT

WINTON AERIAL SEWER GATE

RUMPKE LEACHATE HAULING


METROPOLITAN SEWER DISTRICT
OF GREATER CINCINNATI
CURRENT USER:
REESE JOHNSON
5/3/2016
4:10:37 PM
MSDGC
POLK RUN
SYCAMORE
MILL CREEK
TAYLOR CREEK
INDIAN CREEK
LITTLE MIAMI
MUDDY CREEK

Questions?

Reese Johnson, PE, PMP

reese.johnson@cincinnati-oh.gov

Application of Sensor-Based Networks to Dynamic Simulation and Potable Water Reuse

Tyler Nading, CH2M

Dynamic Simulation and Water Reuse
Project Technologist

Agenda

- ❑ Introduction to Dynamic Simulation
- ❑ Lee Tunnel Project Example
- ❑ West Point WWTP Project Example
- ❑ Online Analyzers for Potable Reuse Source Control
- ❑ Questions (throughout the meeting)

Introduction to Dynamic Simulation

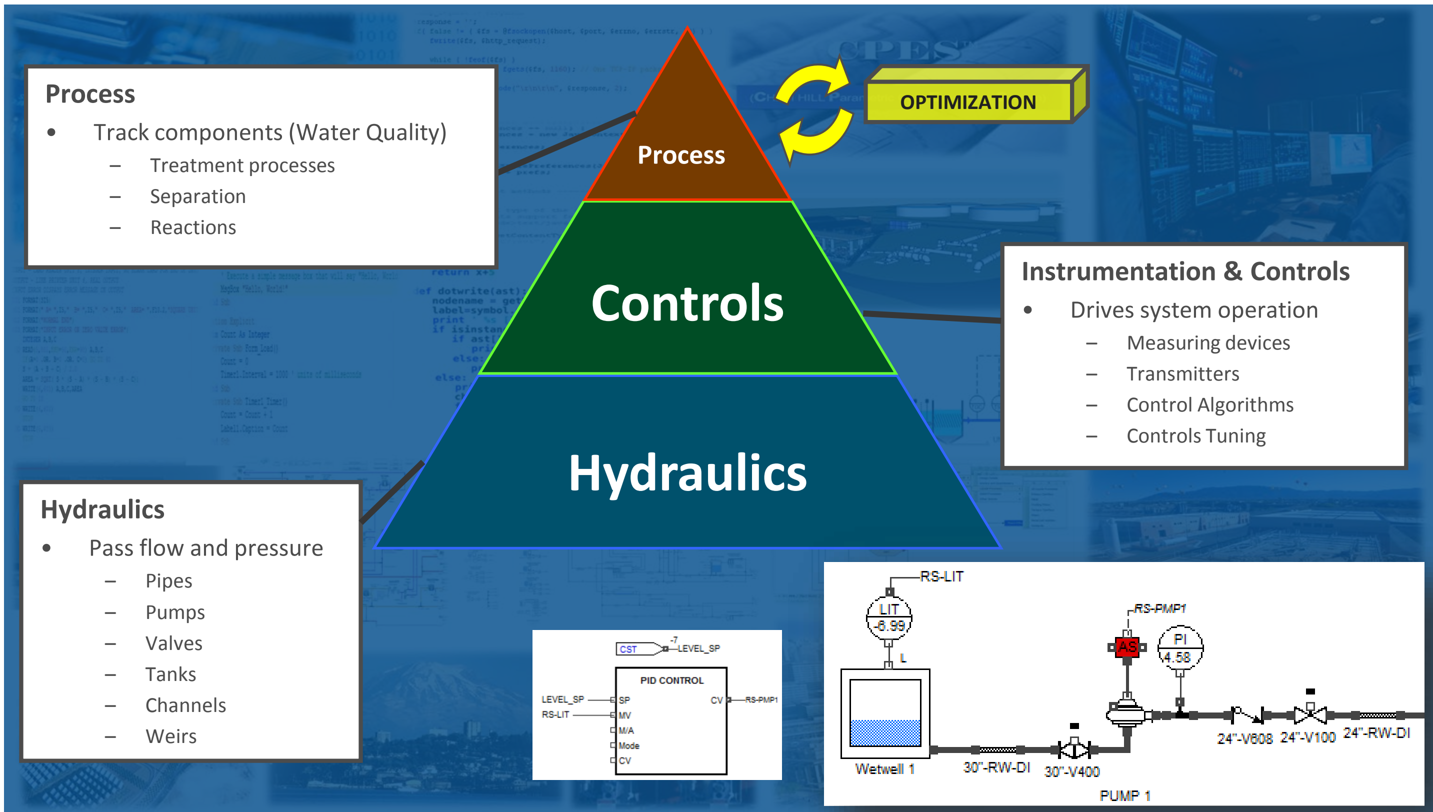
Dynamic Simulation Basics

- What is dynamic simulation?
- Attributes:
  - Simulate a system's behavior progressing through time
  - Conceptualize projects/ideas
  - Optimize system performance
  - Test hypothesis in a safe, low cost environment

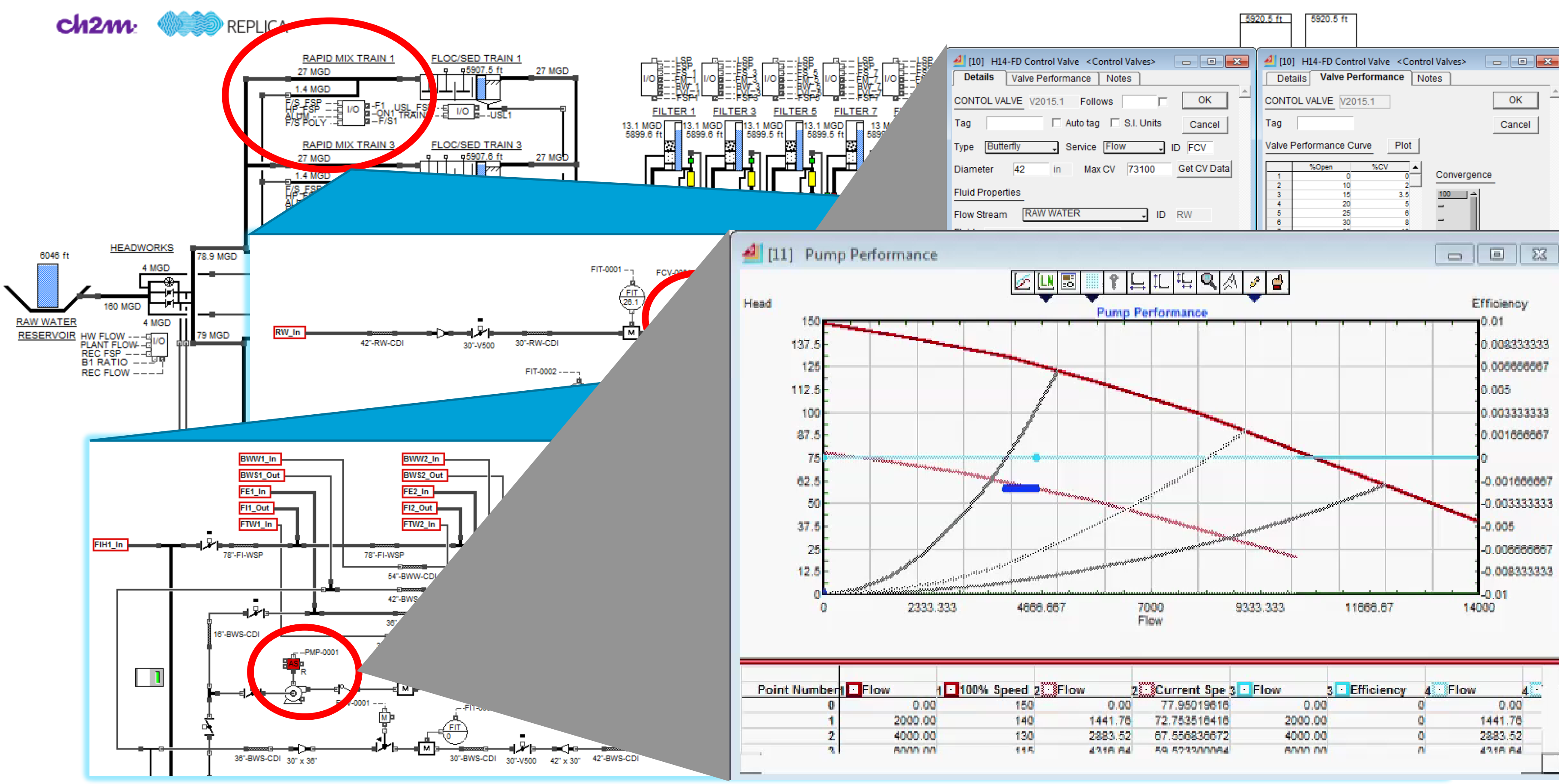
Replica Dynamic Simulation

- Operates in ExtendSIM
- Developed by CH2M from 2001-2005
- Object-oriented dynamic simulation tool developed by CH2M process engineers specifically for:
  - Water conveyance
  - Wastewater collection systems
  - Water and wastewater treatment plants
- Over 100 successful project applications

Replica Dynamic Simulation Architecture



Replica Dynamic Simulation Example Model



Lee Tunnel Project Example

Project Example – Lee Tunnel Operational Analysis

Operational and Control System Optimization

Lee Tunnel

Creating a cleaner, healthier River Thames

- Tunnel under the River Thames in London, UK
  - 5 mile long
  - 20 ft diameter
  - 300 ft underground
- Consent decree by EU to reduce CSO events to the River Thames
- Part of the bigger Thames Tideway program

PROJECT PHASE

DESIGN

- Equipment Sizing & Selection
- Hydraulic Analysis
- Control Strategy Development
- Design Optimisation

Project Example – Lee Tunnel Operational Analysis

Operational and Control System Optimization

PROJECT PHASE

DESIGN

- Equipment Sizing & Selection
- Hydraulic Analysis
- Control Strategy Development
- Design Optimization

CONSTRUCTION

FACILITY STARTUP

- Controls System Testing
- Operator Training Simulator

OPERATIONS

- Offline Operations Analysis
- Offline Optimization
- Online Optimized Control
- Operator Training Simulator

PROJECT PHASE

DESIGN

- Equipment Sizing & Selection
- Hydraulic Analysis
- Control Strategy Development
- Design Optimisation

Project Example – Lee Tunnel Operational Analysis

Operational and Control System Optimization

Challenges

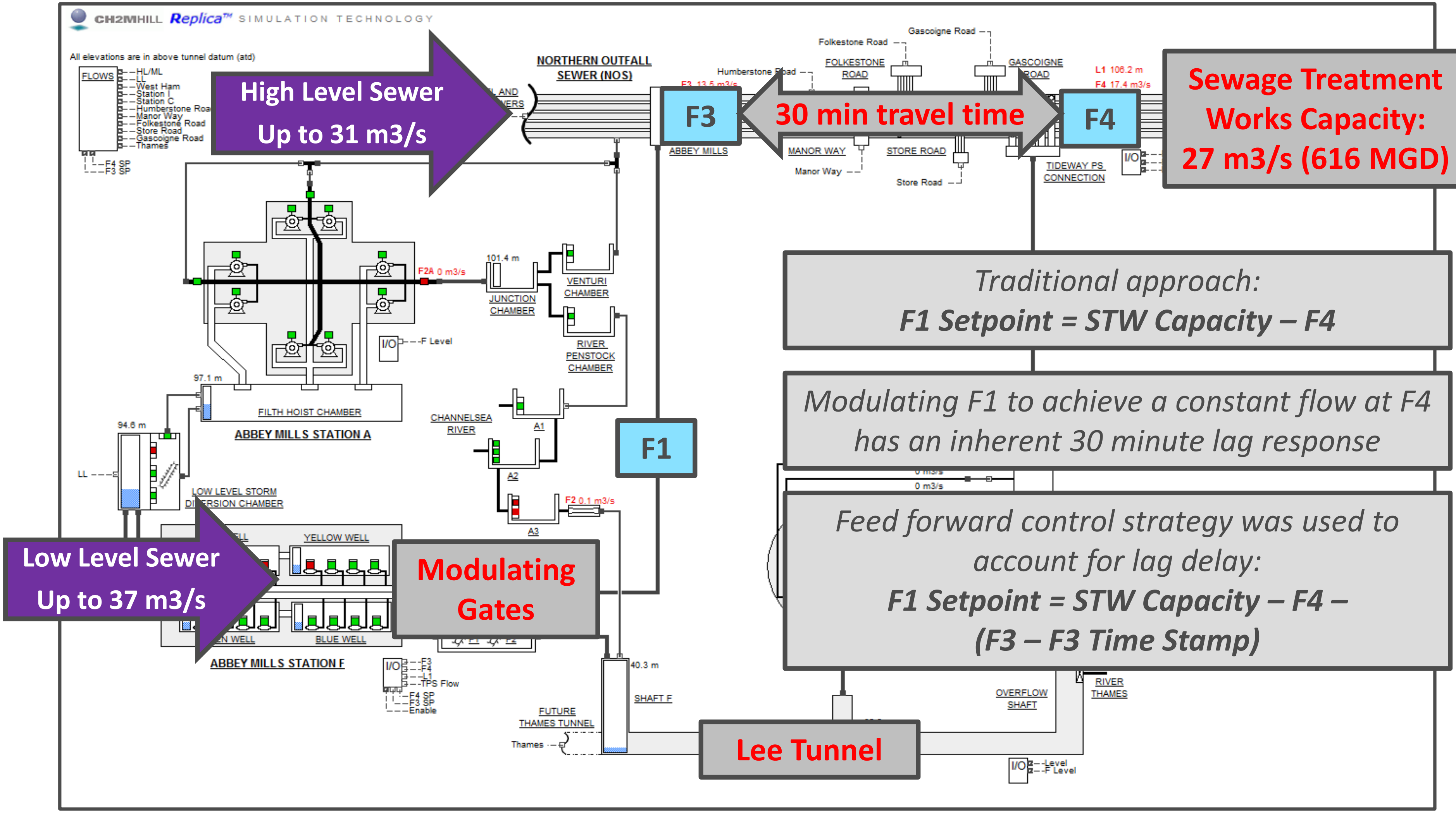
- Unsure how control strategy would function during commissioning
- Financial penalty for unjustified overflow events

Approach

- Utilize dynamic simulation to create optimized control strategy and test against characteristic storm events

Project Example – Lee Tunnel Operational Analysis

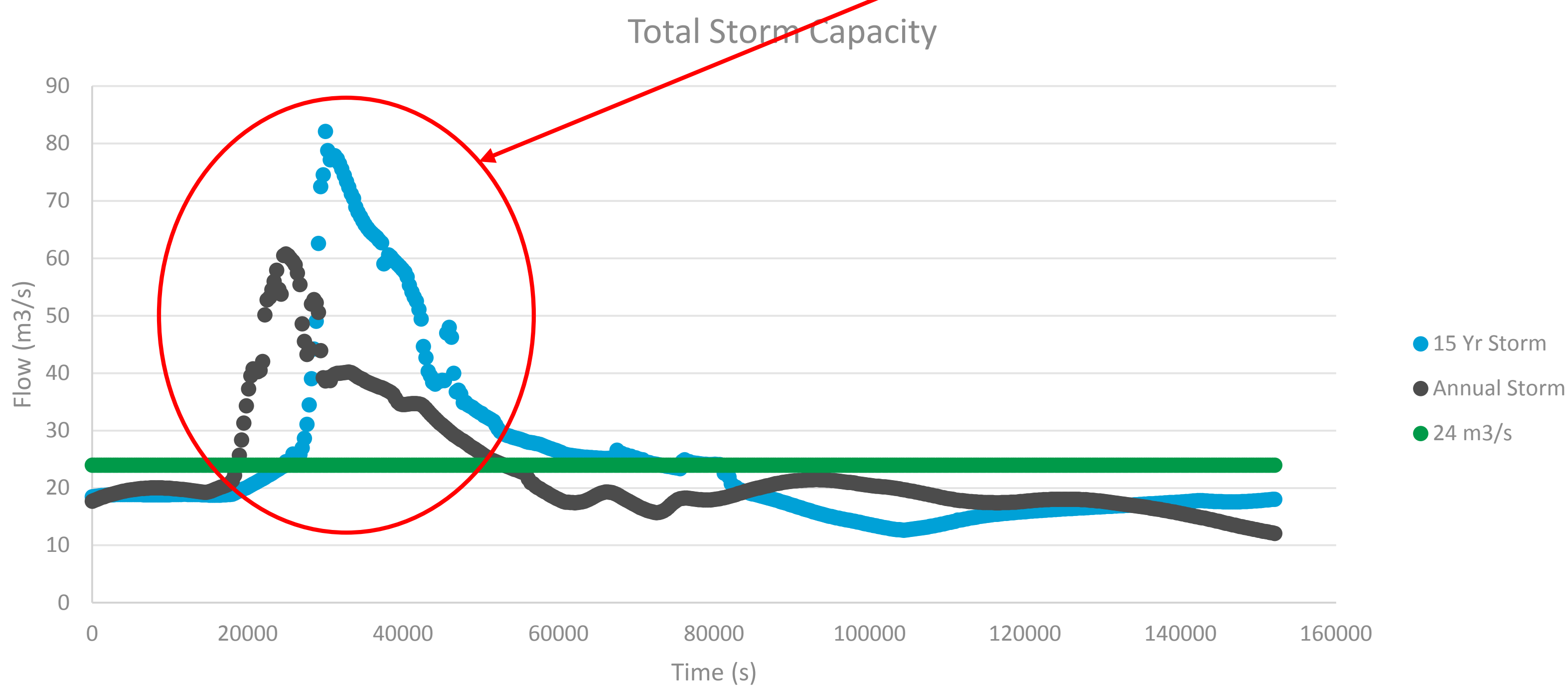
Operational and Control System Optimization



Control Strategy Analysis: Station F Penstocks

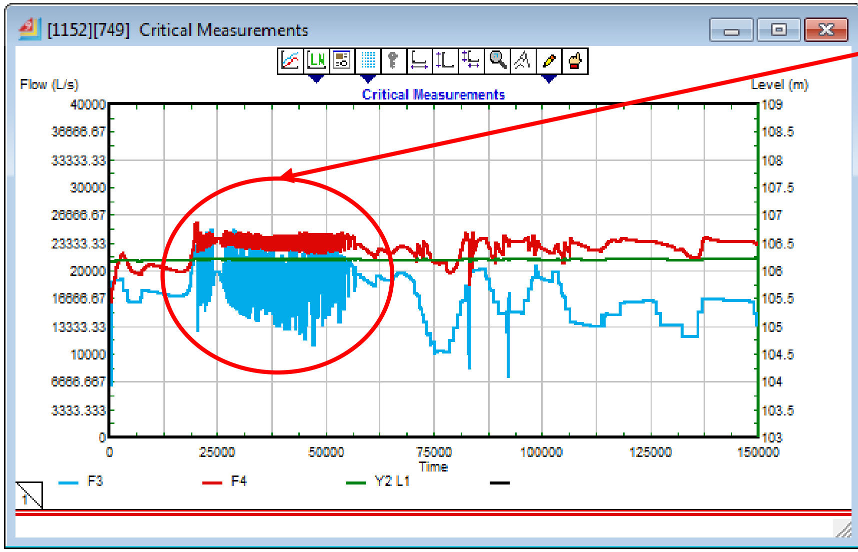
- Flow Data Used From Thames Tideway Team:
  - 15 yr, 120 min storm
  - Typical annual storm
  - Approximately 32 hour simulation

Goal: flatten the peak for the flow going to the STW during and after the storm

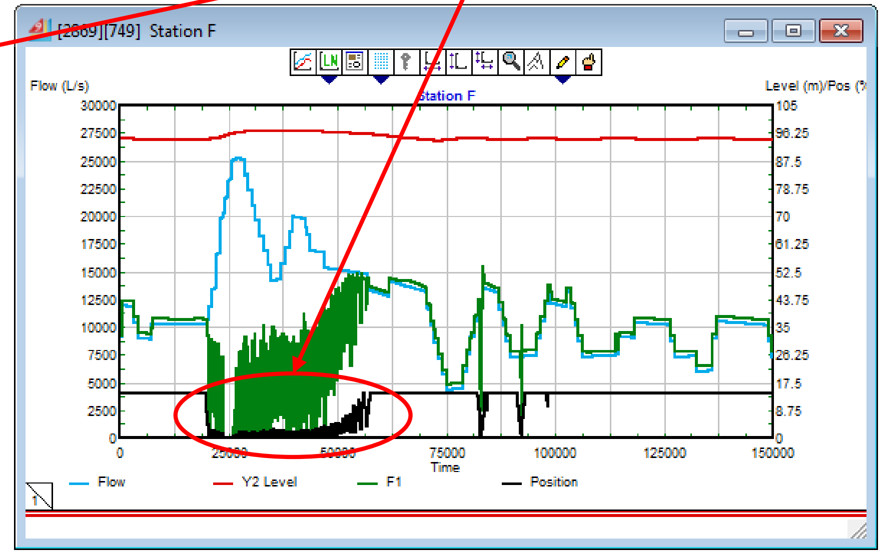


Control Strategy Analysis: Station F Penstocks

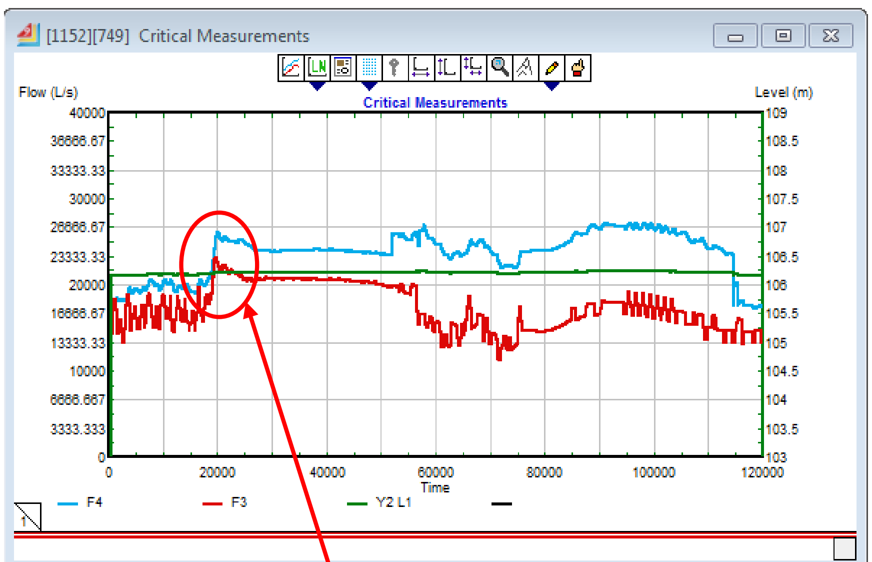
Rapid penstock operation causes wide flow swings at F1, F3, and F4

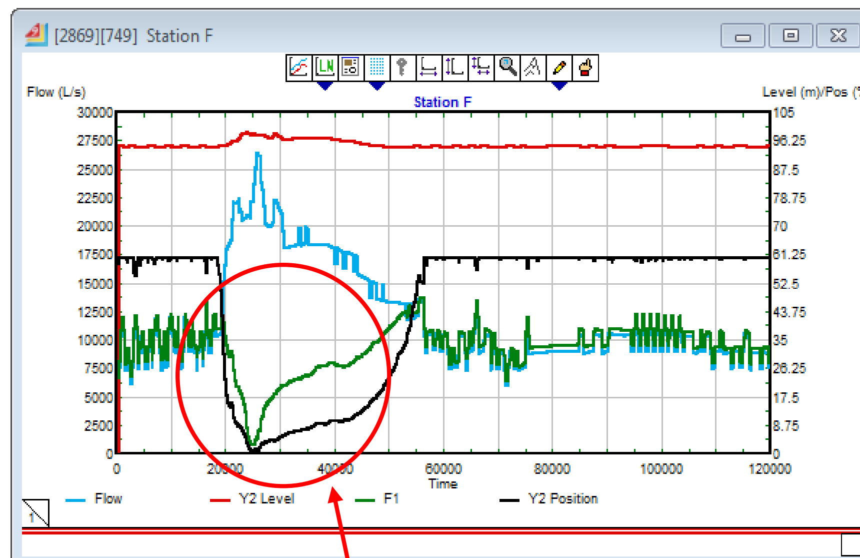


Blue: F3 Flow; Red: F4 Flow



Green: F1 Flow; Blue: Station F Pumped Flow; Black: Gate Position





During peak of storm, F4 is consistent at 24 m^3/s and max stays below 24.5 m^3/s

Penstock modulation allows for consistent F4 Flow

PROJECT PHASE

DESIGN

- Equipment Sizing & Selection
- Hydraulic Analysis
- Control Strategy Development
- Design Optimisation

Project Example – Lee Tunnel Operational Analysis

Operational and Control System Optimization

Importance of Sewershed Monitoring

✓Accurate flow measurement in old, brick sewers

✓System-wide real-time controls over a 10 mile distance

✓Water quality monitoring to prevent underground storage from going septic

PROJECT PHASE

DESIGN

- Equipment Sizing & Selection
- Hydraulic Analysis
- Control Strategy Development
- Design Optimisation

Project Example – Lee Tunnel Operational Analysis

Operational and Control System Optimization

Outcomes

- ✓Provided advanced control strategy that optimizes sewage going to STW
- ✓Tested control strategy against various storm events to verify system operation
- ✓Reduced risk of overflowing at STW when tunnel is empty

West Point WWTP Project Example

Project Example – West Point WWTP

Operational and Control System Optimization

PROJECT PHASE

DESIGN

- Equipment Sizing & Selection
- Hydraulic Analysis
- Control Strategy Development
- Design Optimization

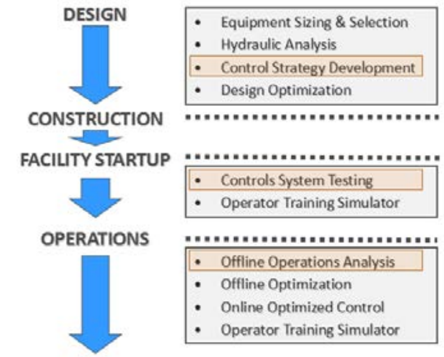
CONSTRUCTION

FACILITY STARTUP

- Controls System Testing
- Operator Training Simulator

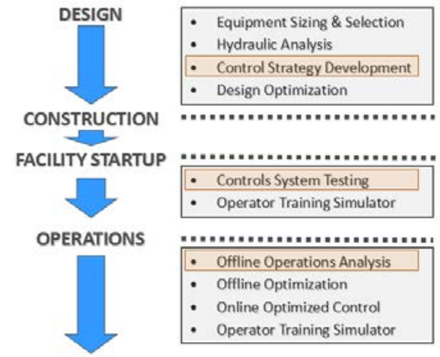
OPERATIONS

- Offline Operations Analysis
- Offline Optimization
- Online Optimized Control
- Operator Training Simulator



Project Example – West Point WWTP

Operational and Control System Optimization



Challenges

- Operations due to tightly coupled critical hydraulic elements
- Cutover of IPS from existing PLC to new Ovation (DCS) system

Approach

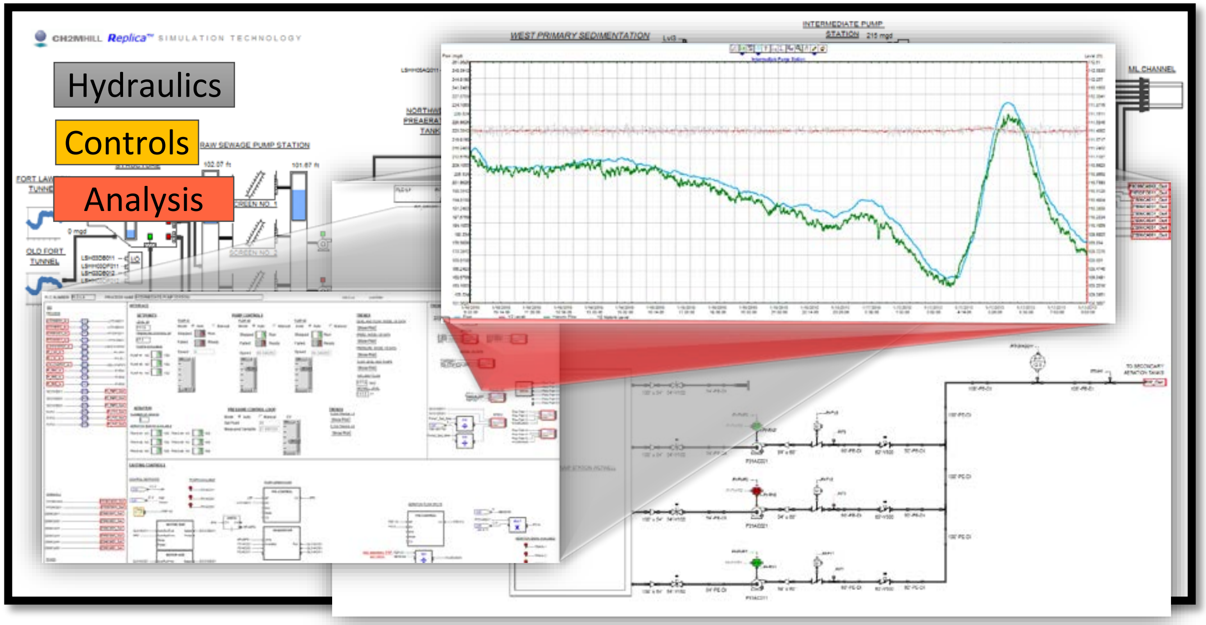
Utilize Replica dynamic simulation modeling to help:

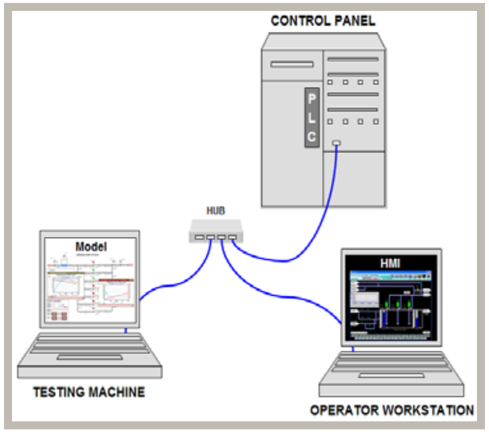
- Mitigate closely coupled hydraulics by optimizing control algorithms
- Test programmed control logic before implementation

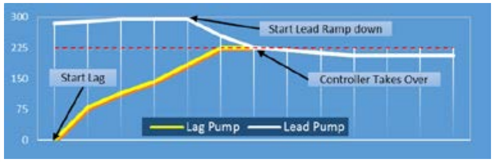
Project Example – West Point WWTP

Operational and Control System Optimization

440 MGD/1665 MLD Capacity (secondary capacity of 300 MGD/1135 MLD)

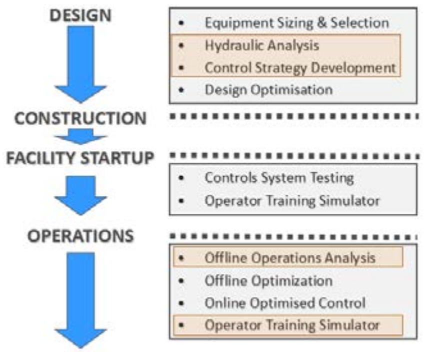






Project Example – West Point WWTP

Operational and Control System Optimization

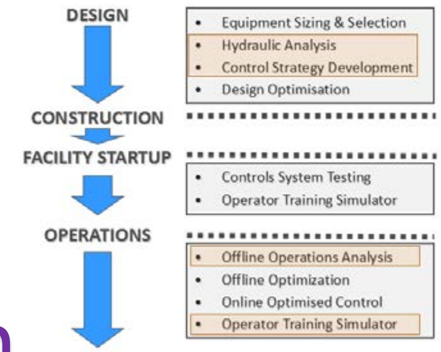


Outcomes

- ✓Model provided to client for what-if scenario analyses
- ✓Dynamically linked the Replica model to the Ovation system for control testing at FDS and IPS, and EPS before cutting from PLC to Ovation.
- ✓Smooth cutover from existing PLC to new Ovation control system
- ✓Reduced risk of non-permitted bypass and increased operability of IPS during extreme rain events
- ✓Operator buy-in: allows automated controls to dictate pump transitions

Project Example – West Point WWTP

Operational and Control System Optimization



Importance of Dynamic Simulation

✓Reduce risk

✓Make informed decisions

✓Industry is moving towards:

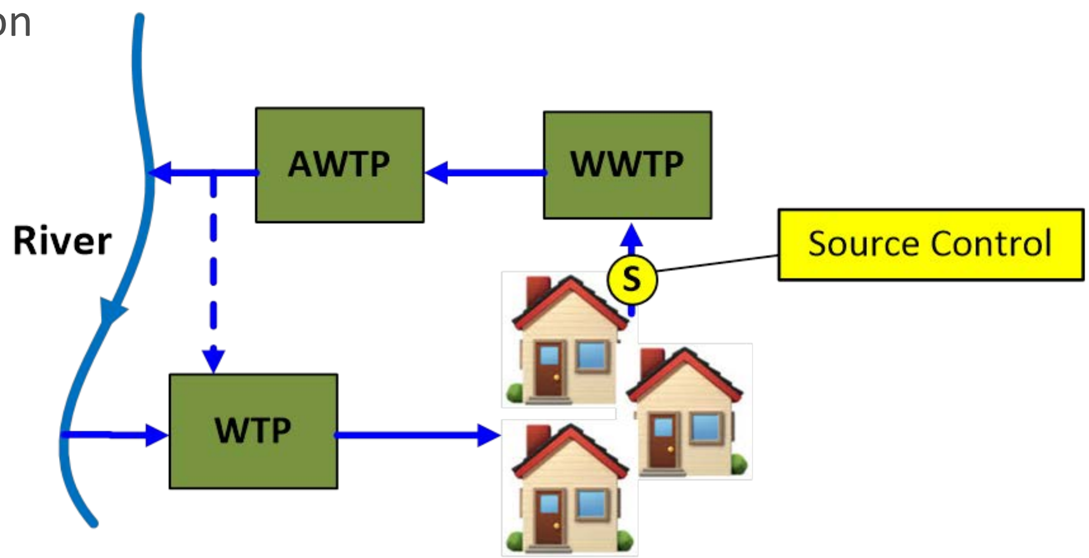
- Better operator training
- Flight simulators
- Real-time controls

Rely on various applications of real-time analyzers in sewershed and within treatment plant

Online Analyzers for Potable Reuse Source Control

Potable Reuse Source Control

- Currently regulated by EPA to prevent pollutants from entering WWTP that can:
  - Interfere with WWTP processes
  - Pass through WWTP
- With trend towards potable reuse, agencies are taking a deeper look at source control
- Goal: limit potential for collection system upsets to pass through WWTP and AWTP and compromise public health



Potable Reuse Source Control: Online Monitoring

- The best way to ensure there are no upsets in the collection system is with online monitoring
- Singapore PUB uses online VOC analyzers to detect illegal industrial discharges
- For potable reuse, the parameters of concern don't have online technology
    - Pathogens
    - Trace organics (PPCPs)
- Many utilities use a combination of analyzers (UV254, conductivity, TSS/turbidity) as surrogates for upstes
    - Real-time data analytics of analyzers is required to detect upsets
- One of the biggest growth areas for potable reuse!

Thank you!

Tyler.Nading@ch2m.com

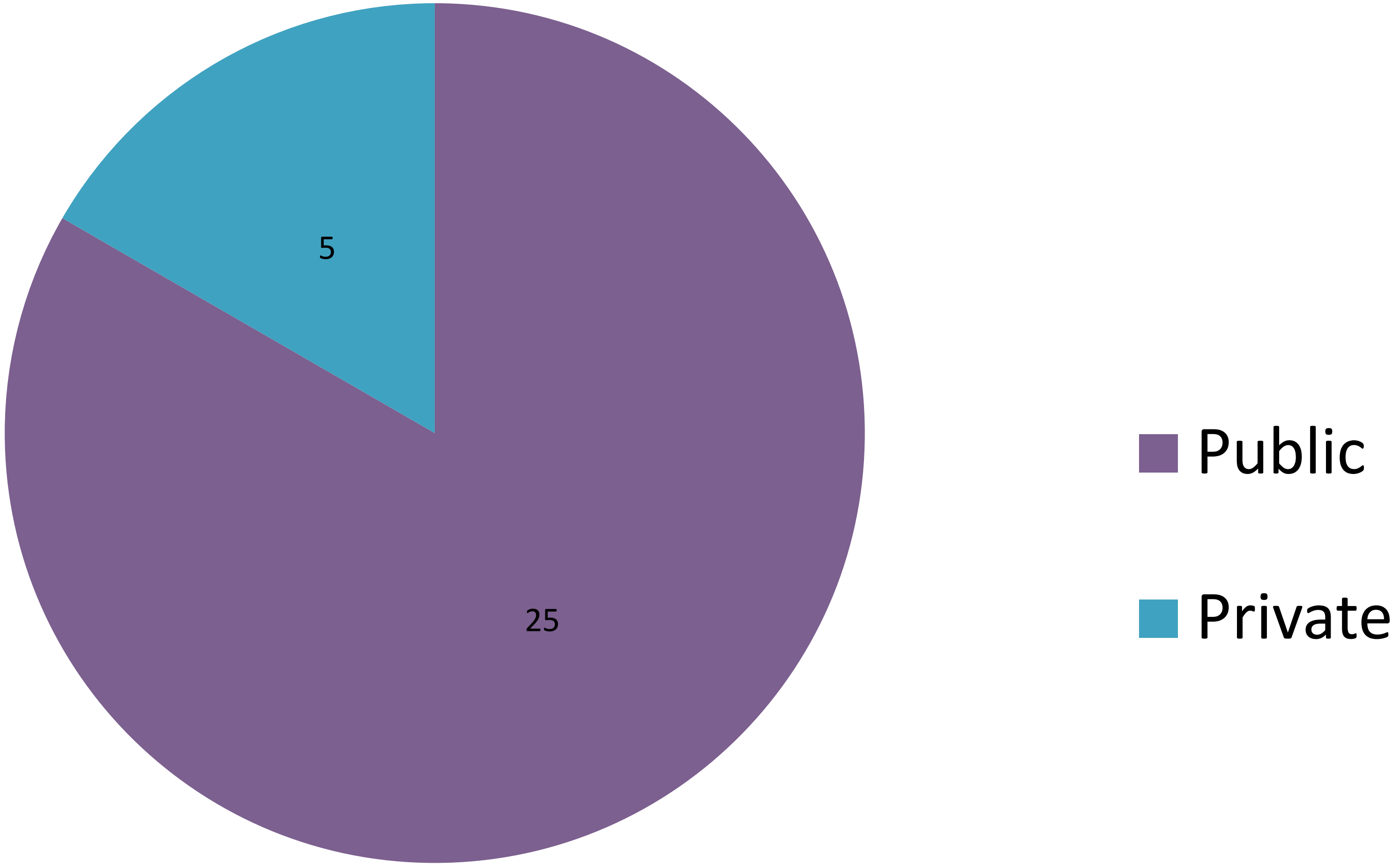
Questions?

Report for Big Data Management Survey - Utilities

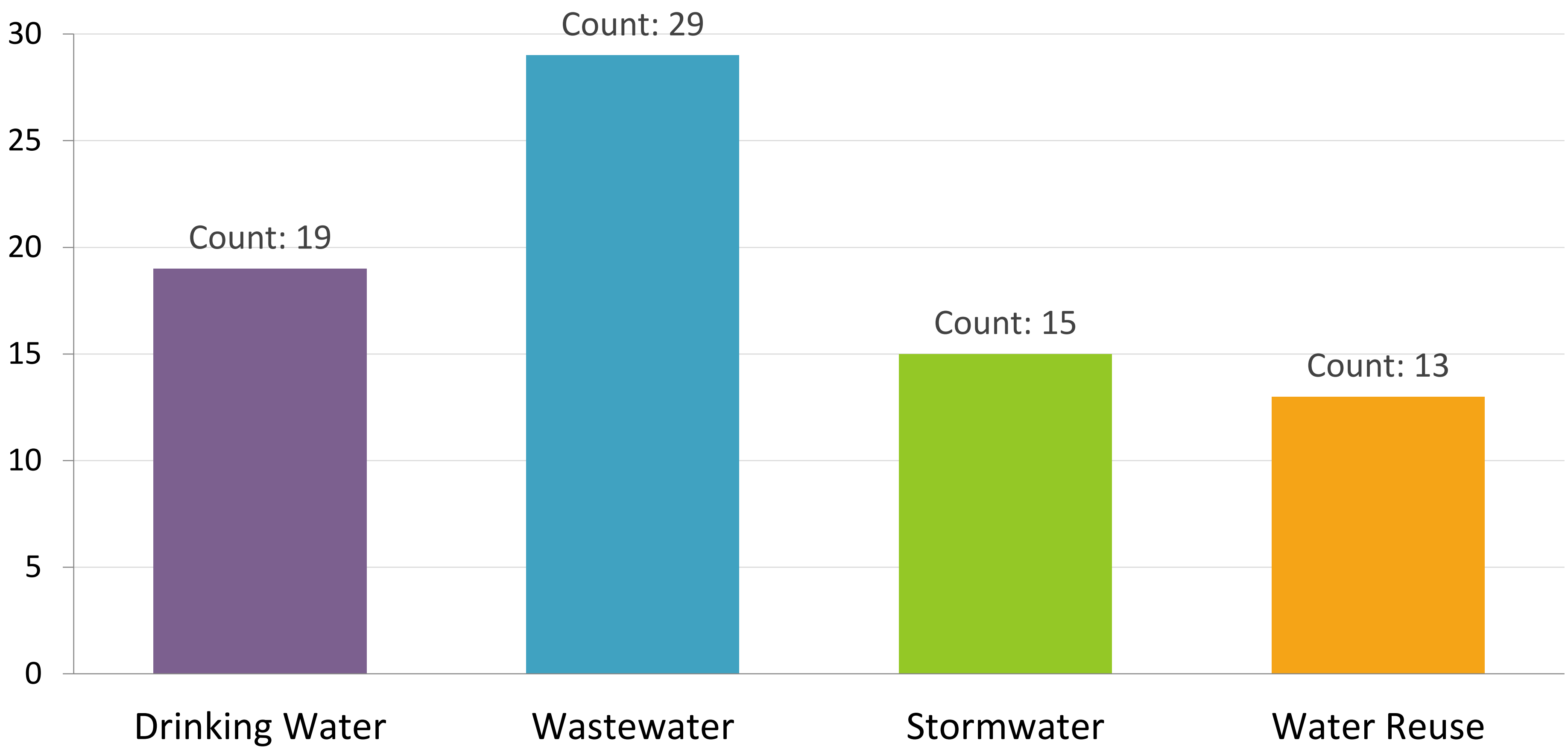
Utility Participant Background

- **30** respondents
- 23 Utilities from US, 3 from Europe, 2 from Asia, 1 from Australia, and 1 from South America
- Sections
  - Who are you
  - Challenges
  - What are you doing now
  - Future activities

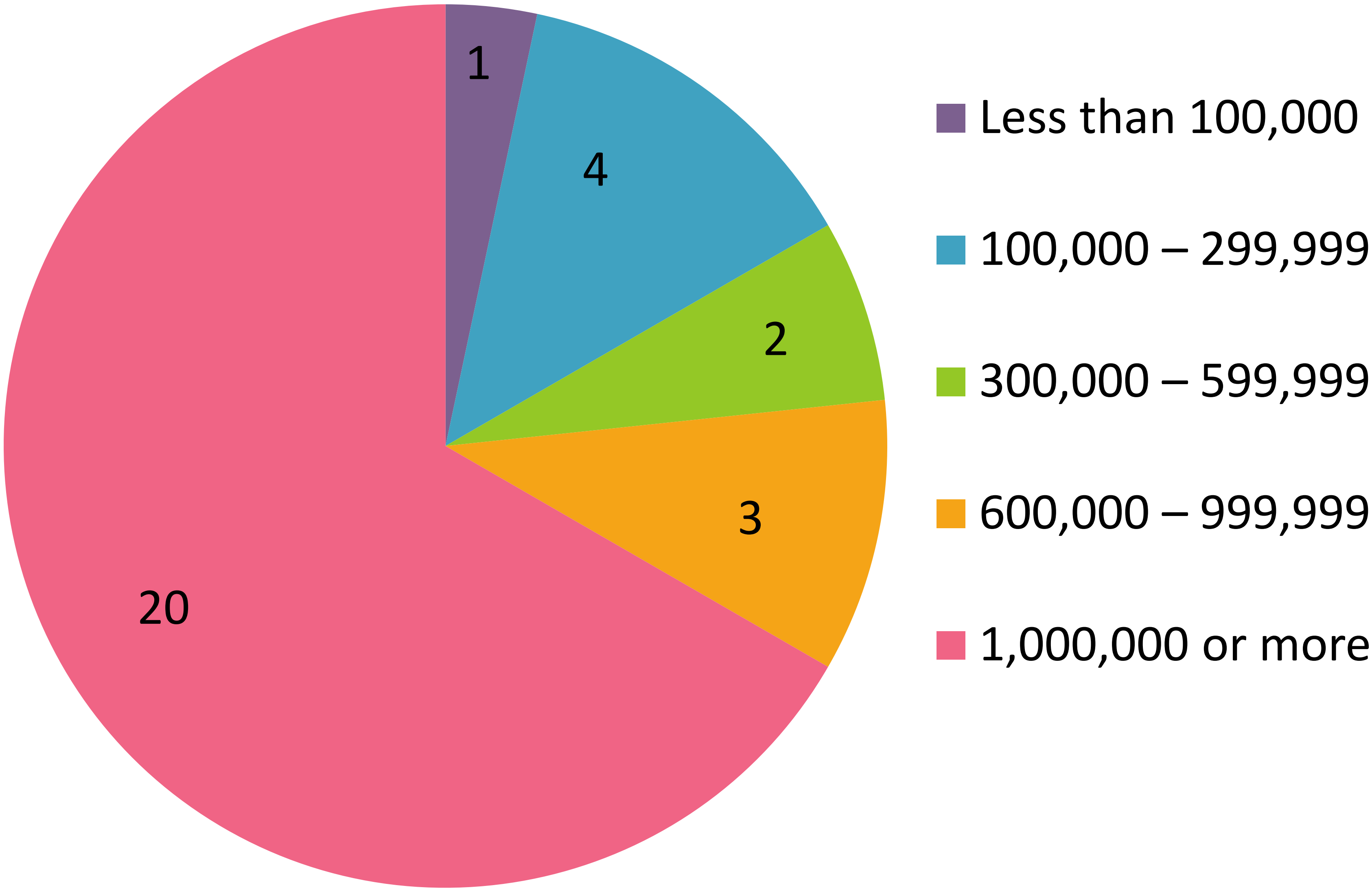
Is your utility a public or a private entity?



What types of facilities does your utility currently manage? Please select all that apply.



What population does your utility serve?



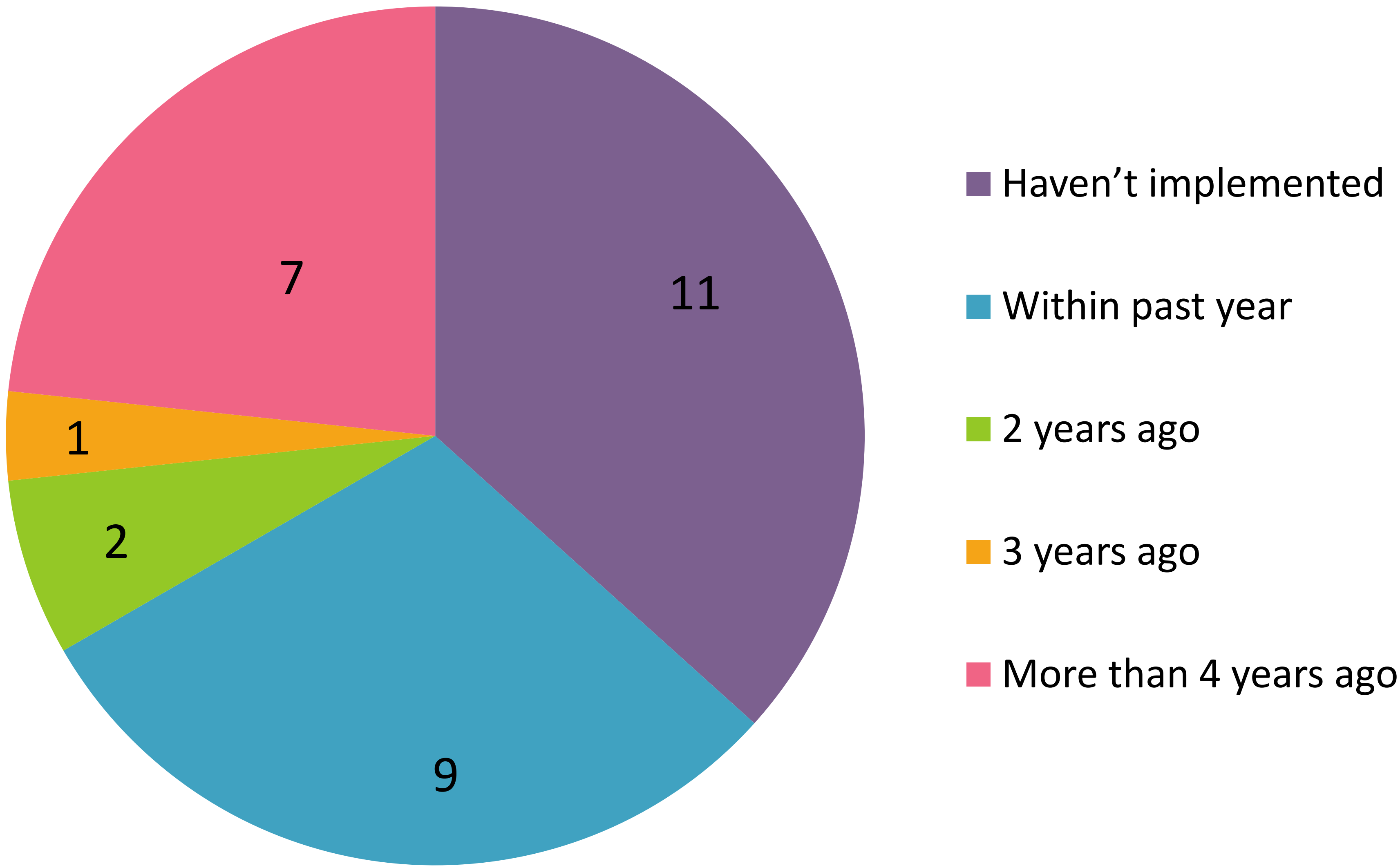
Please rate current challenge level for your utility (Adjusted to a Low-Med-High rating).

	Low	Med	High
	Count	Count	Count
Aging of utility infrastructure	0	6	24
Managing capital costs	2	12	16
Managing operational costs	3	10	17
Justifying improvements/rate requirements	3	11	16
Resilience/Reliability	5	9	15
IT infrastructure (servers, network, storage)	5	12	13
Data management (databases, visualization and analysis tools)	7	6	17
Industrial control systems (SCADA, PLCs, DCS)	6	11	13
Aging workforce	3	5	22
Treatment technology	12	11	7

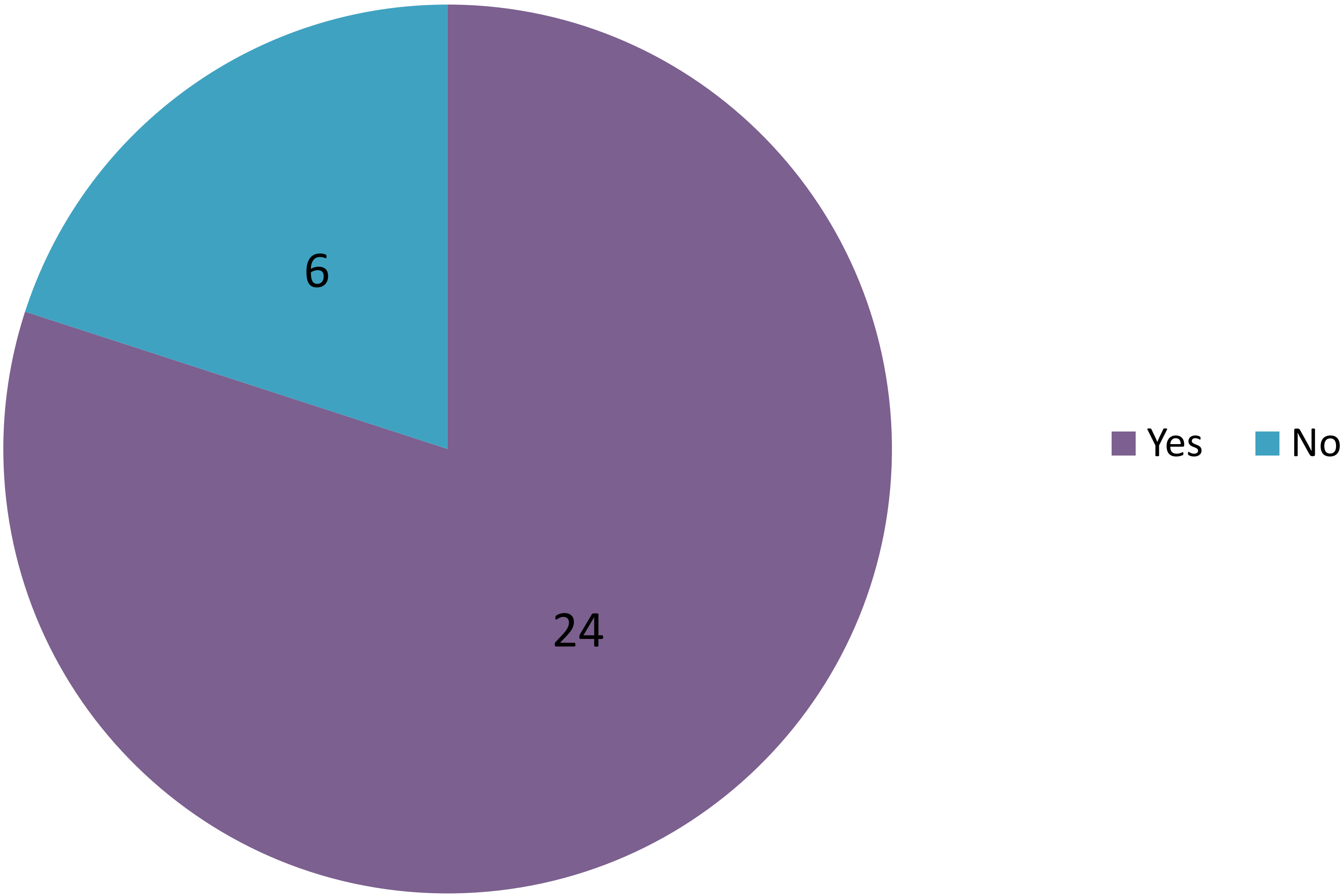
Please rate current challenge level for your utility. Cont'd

	Low	Med	High
	Count	Count	Count
Water conservation	15	5	10
Political will to establish sustainable rates	6	14	10
Availability of funding	9	11	10
Water scarcity or availability	16	5	9
Water loss (Non-revenue water)	11	11	7
Cross-connections or redundancy	15	13	1
Meeting treated water discharge regulations	13	9	8
SSO and/or CSO occurrences within the system	8	10	12
Customer satisfaction and raising awareness	5	11	14
Managing stormwater runoff with green stormwater infrastructure	13	12	5

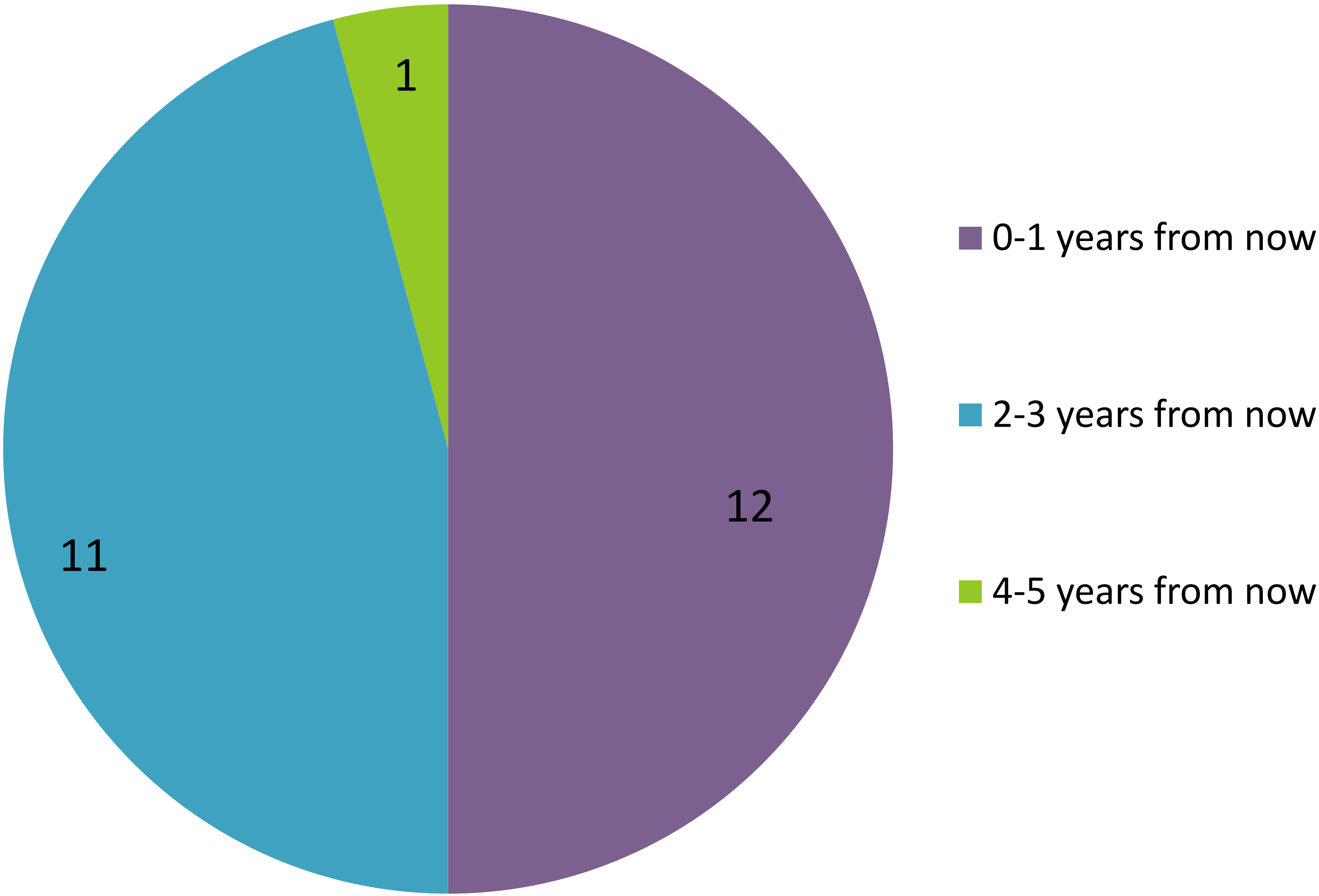
Has your utility implemented components to store and process Big Data? If YES, when did you implement it?



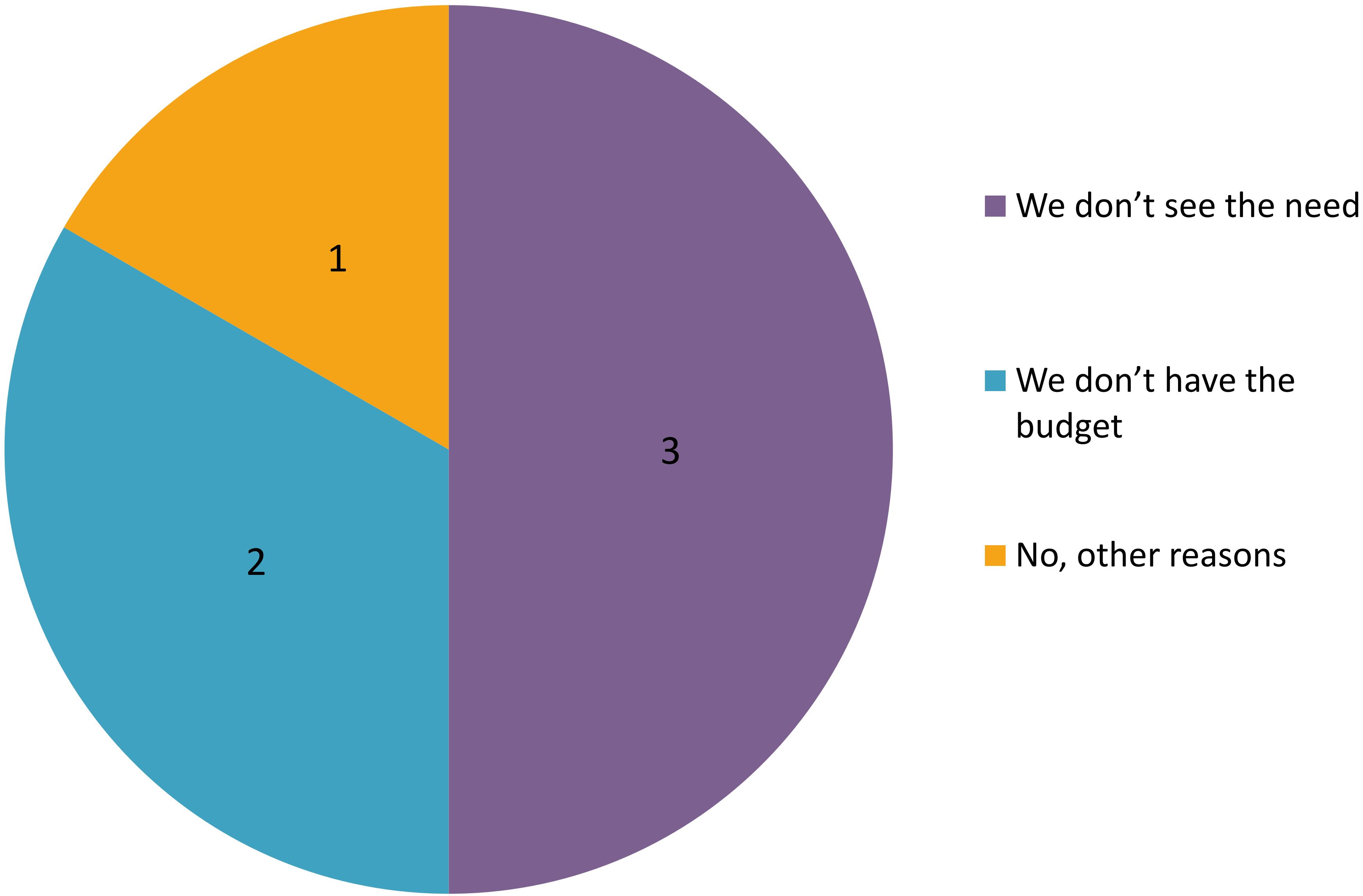
Does your utility plan to have or increase Big Data investments in the near term?



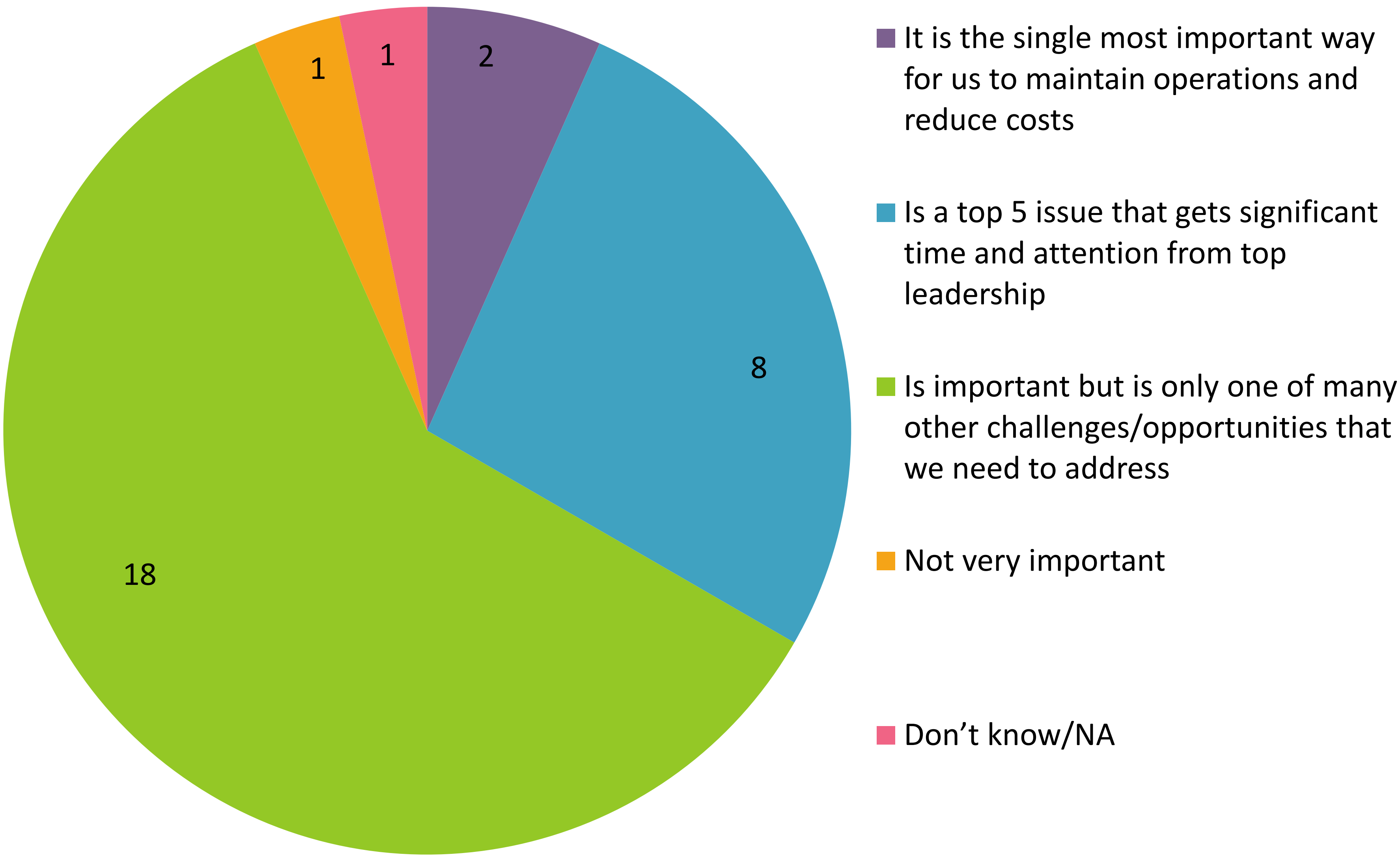
If YES, when do you see your utility will have or increase investment on Big Data?



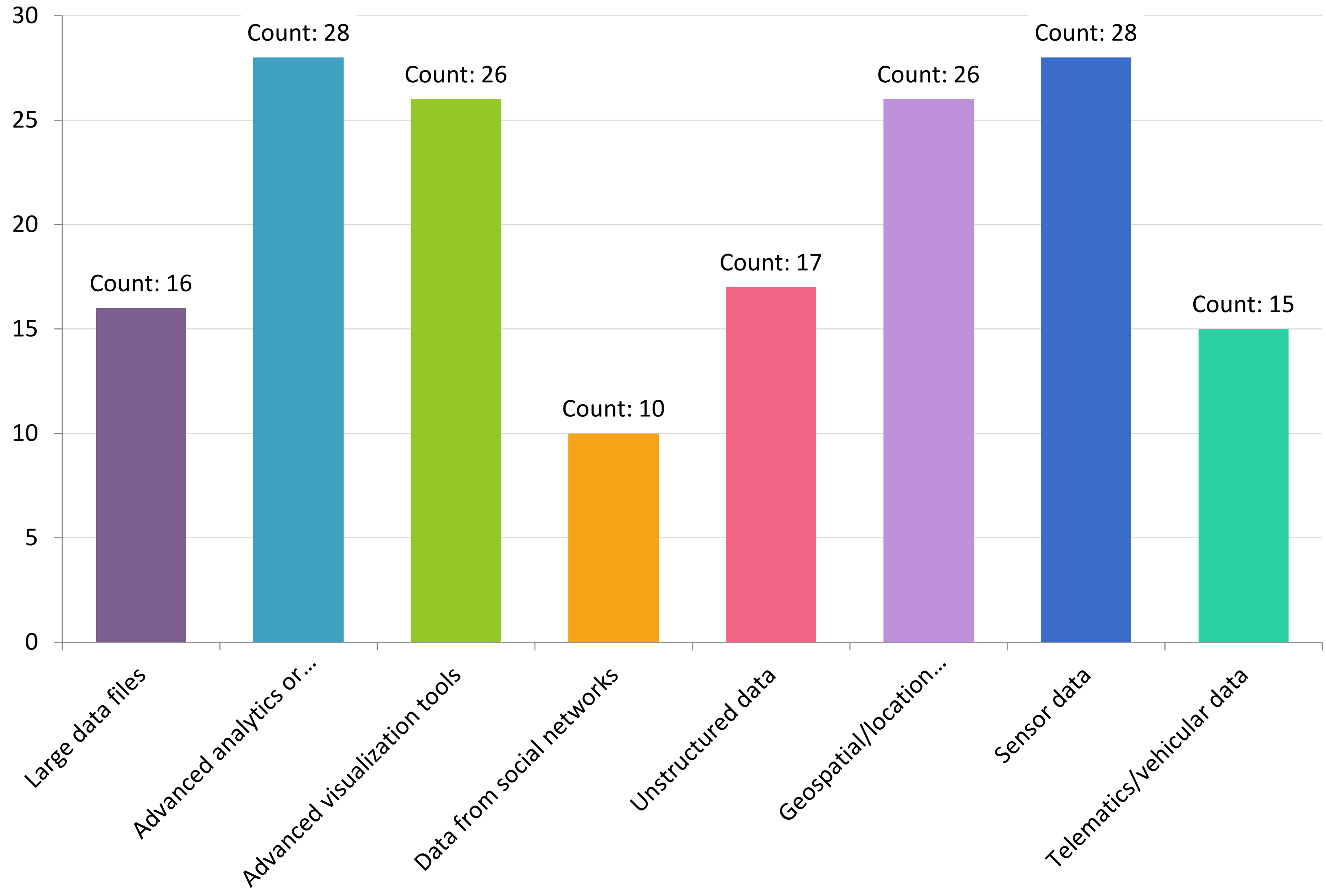
If NO, what's the reason for not investing in Big Data?



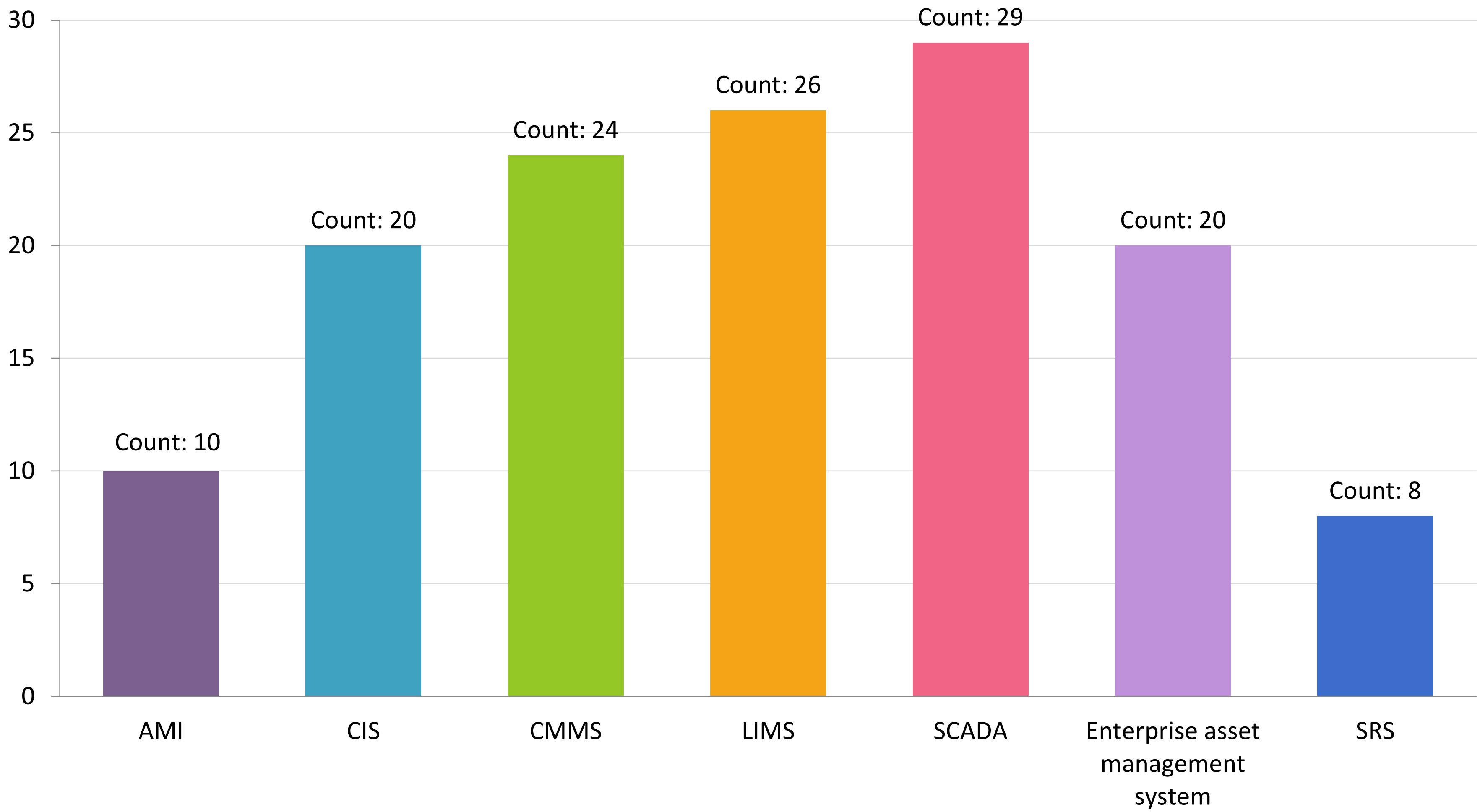
How important is Big Data analysis to your utility?



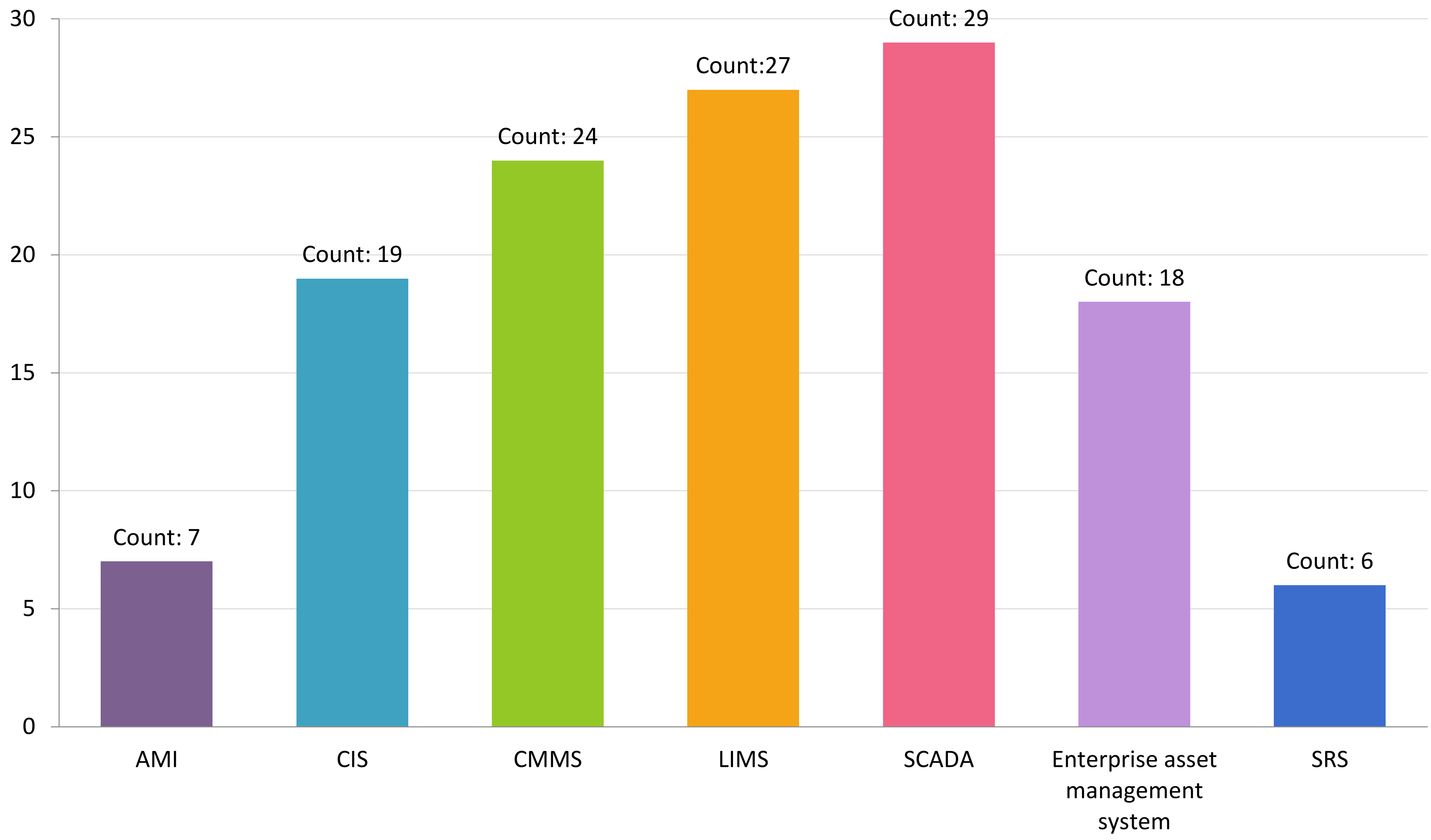
Which of the following do you consider as part of Big Data? Please select all that apply.



What system(s) below have you already implemented in your utility? Please select all that apply. (SRS definition link: EPA SRS Introduction)



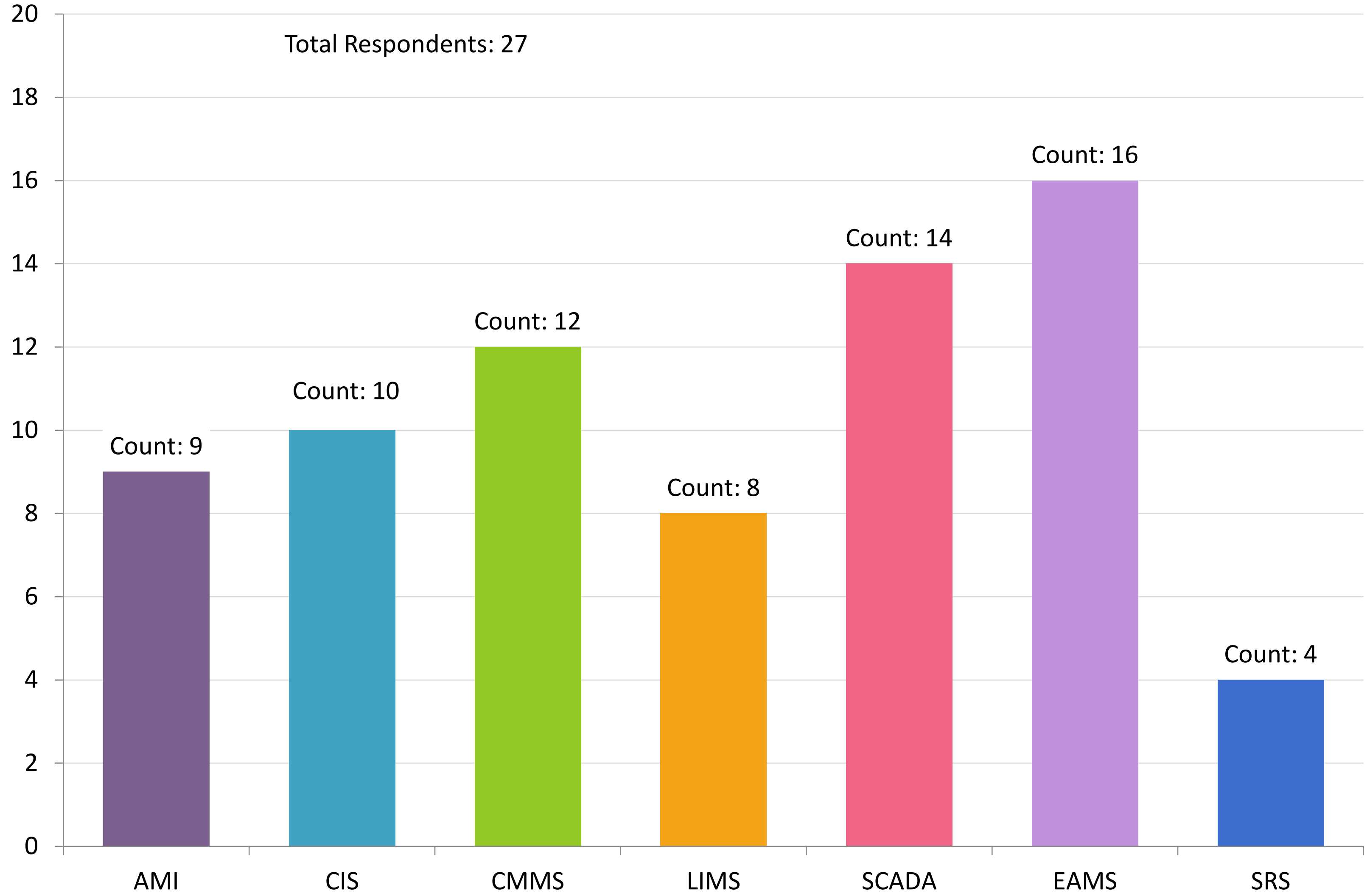
Which system(s) does your utility use on a daily basis? Please select all that apply.



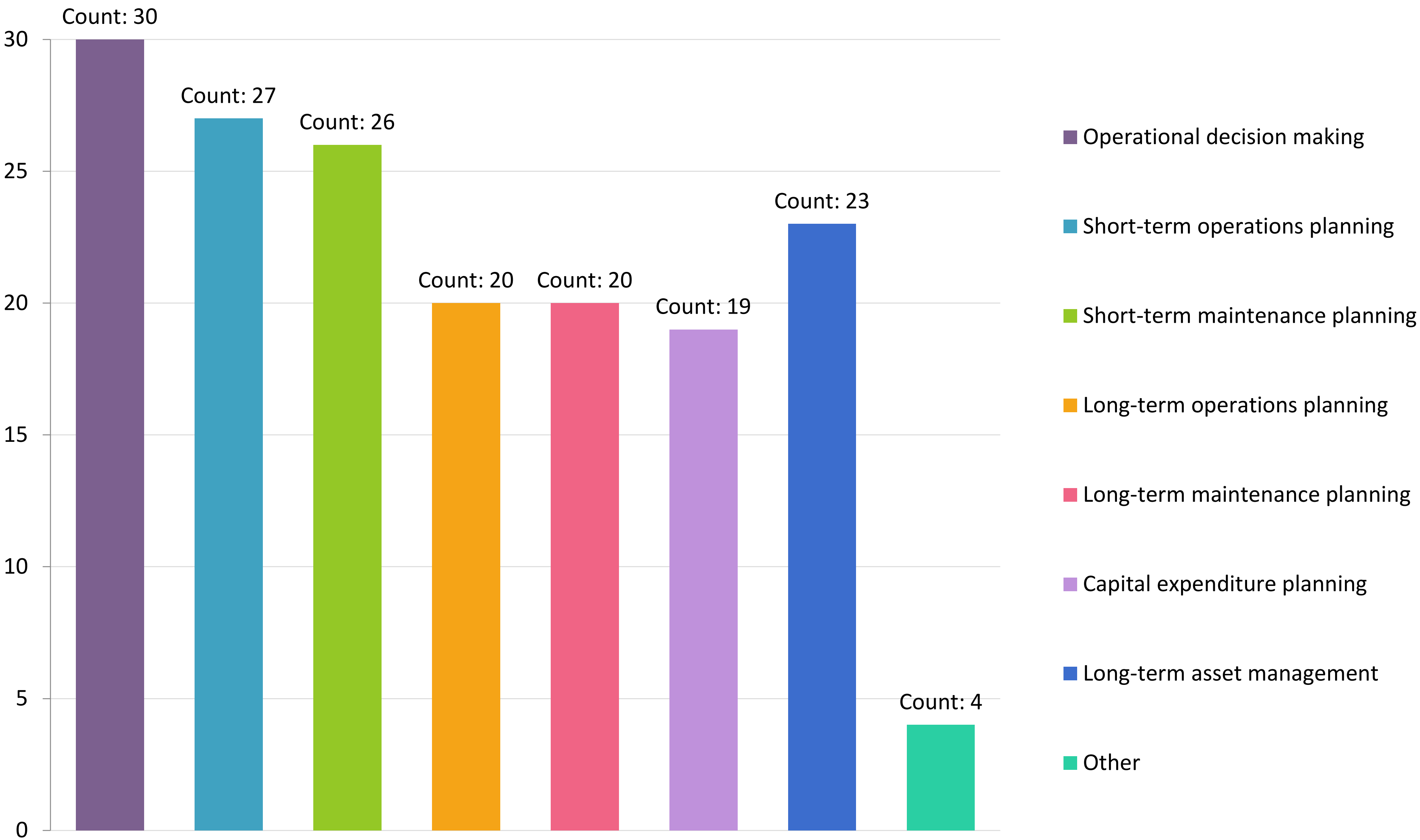
How important are the below systems to your utility

	Low	Med	High
	Count	Count	Count
Advanced metering infrastructure (AMI)	14	3	12
Customer information system (CIS)	9	0	20
Computerized maintenance management systems (CMMS)	2	1	27
Laboratory information management systems (LIMS)	2	2	26
Supervisory control and data acquisition (SCADA) system	0	0	30
Enterprise asset management system	5	4	21
Surveillance and Reponses System (SRS)	14	7	8

What system(s) below is your utility most likely to implement, upgrade or extend in the near future? Please select all that apply.



What does the information from these systems get used for? Please select all that apply.



Please rate the importance of each of the following benefits of Big Data analysis will bring to your utility

	Low	Med	High
	Count	Count	Count
Optimal operation of treatment plants and networks,	3	2	25
Predict system and equipment failure	1	5	24
Accelerate the speed with which new capabilities and service are deployed	5	10	15
Decrease expenses through operational cost efficiencies	1	5	24
Mitigate knowledge loss from aging workforce	1	9	20
Improve workforce management	2	4	24
Extract greater value from existing analytical tools	3	5	22
Reduce non-revenue water to minimize water and revenue losses	12	3	14
Reduce pollution events	8	9	13

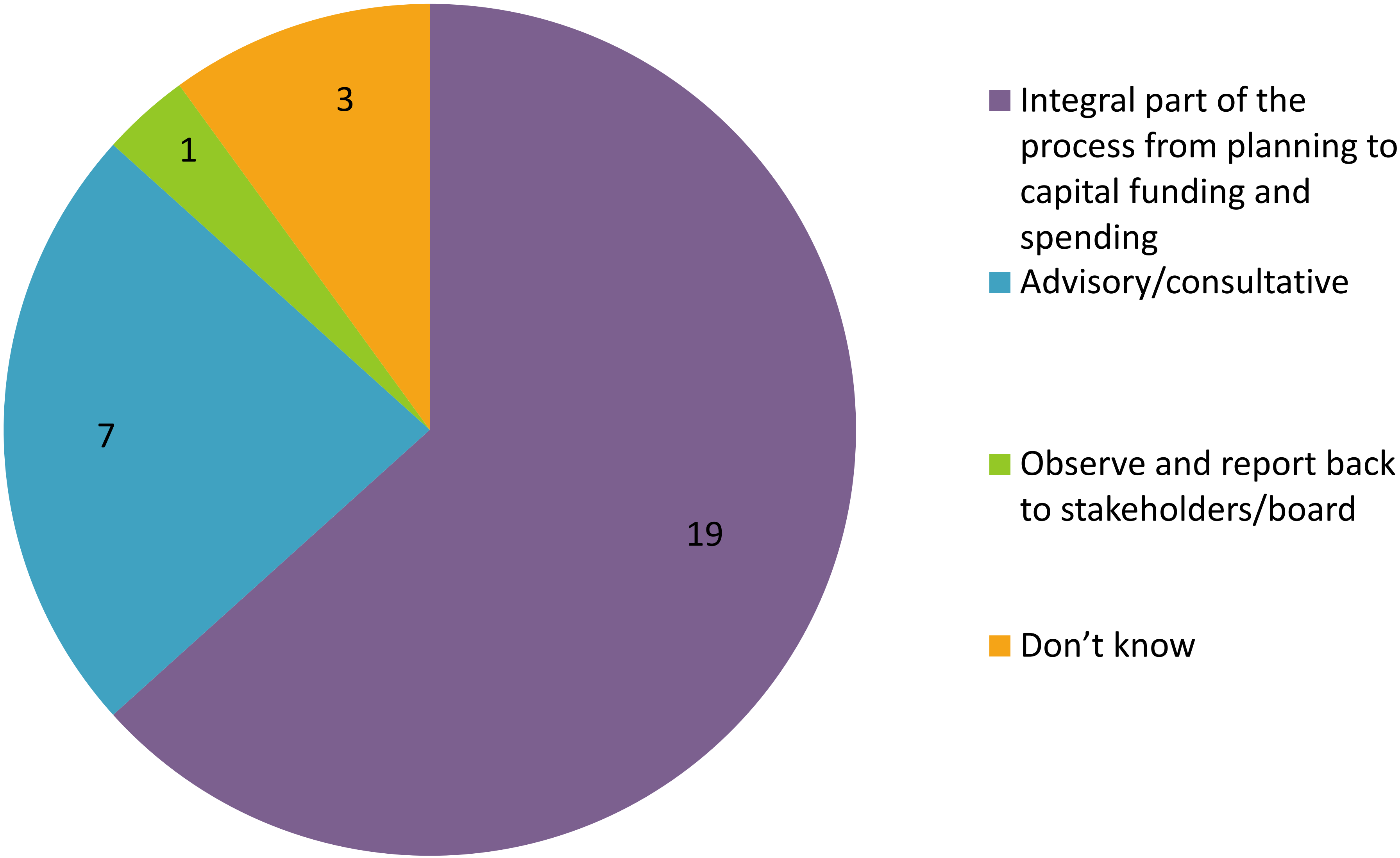
Please rate the level of skills available within your utility for each of the following

	Low	Med	High
	Count	Count	Count
Management (storage, indexing and retrieval) of Big Data	5	10	15
Off-line analysis of Big Data	13	8	9
Real-time analysis of Big Data	16	10	4
Maintenance of systems to manage and analyze Big Data	8	11	11

Please rate the level of Big Data's impact on each of the following areas of your utility in the next five years

	Low	Med	High
	Count	Count	Count
Impacting customer relationships	5	6	19
Changing the way we organize operations	4	3	23
Making the business more-data-focused	3	4	23

What do you see as the water utility’s role in developing “smart cities"?



Please rate the level of influence of each of the following impediment factors have on Big Data analysis adoption in your utility

	Low	Med	High
	Count	Count	Count
Data security	5	8	17
Data quality	0	8	22
Lack of budget	7	12	11
Lack of talent to implement big data	5	8	17
Lack of talent to run big data processing and analytics on an ongoing basis	5	4	21
Resistance to integrate existing systems	6	12	12
Procurement limitations on big data vendors	15	12	3
Lack of middle management adoption and understanding	5	15	10
Lack of data governance policies and practices	7	14	9

Attachment D –
Summary of Breakout Session Outcomes

Group Exercise: Identify IoT Gaps in the Water Sector

Participants were divided into two groups for this task. The Internet of Things gaps identified have been grouped by topic.

IoT Education

The groups identified the following gaps that relate to education to support the implementation of IoT:

- Information technology (IT) educational resources
- Focused university curriculum
- Community of practice – share ideas across water sector
- Utility guidelines – how to get started

Cost of IoT

The groups considered that defining and communicating the cost and benefits of implementing IoT needs further work to cover the following topics:

- Public awareness – explaining the value proposition
- Content to ”de-risk” risk factors associated with implementation. What is the risk of not implementing?
- Push solution costs from capital expenditure to operational expenditure, which will require different business models

Technical Issues and Applications

The groups identified the following:

- IoT architecture – how to communicate, how to centralize, how to process
- Lack of understanding of key concepts: analytics, data engineering, data sciences, deep learning
- Asset management <> IoT (asset performance management – APM)

Breakout Groups: Identify Potential Use Cases

The two groups were then given the task of brainstorming potential use cases for IoT in water and wastewater utilities. The groups identified the following potential use cases:

1. Tracking of industrial users
2. Watershed approach to monitoring
3. Managing river/surface water quality
4. SSO mitigation
5. Water quality – chlorine residual monitoring
6. Auto-trigger sampling
7. Use of drones for temperature/pollutant tracking in source or receiving waters
8. Dynamic silt monitoring/estimating
9. Detect inflow & infiltration (traditional stormwater)

10. Detect elevated groundwater intrusion
11. Correlation between weather events and overflow events, and operational data to overflow events (deep learning)
12. Optimize drinking water storage and still meet demand, firefighting needs
13. Identification/prediction of nitrification within chloraminated systems
14. Reduce risk liabilities due to hydrogen sulfide (H_2S)-related vegetation damage
15. Drive more efficient asset management
16. Failure prediction
17. Real-time modeling driven with real-time sensor data
18. NRW
19. Sensor placement optimization
20. Improving physical security

Other points of note discussed included these:

- Wastewater themes include lowering costs and reducing overflows
- User groups and vendors coming together will assist with IoT application

Breakout Groups: Define Top Five Use Cases

Each group then reflected and identified its Top Five use cases. The numbers in square brackets ([ ]) relate to the numbered items from the previous exercise.

The top five use cases from Group 1 were as follows:

1. Correlation between weather events and operational data to overflow events (deep learning) [11]
2. Driving more efficient asset management/failure prediction [15/16]
3. Identification/prediction of nitrification within chloraminated systems and NRW [13/18]
4. Real-time modeling driven with real-time sensor data [17]
5. Advanced analytics for source water protection [3]

The top five use cases from Group 2 were as follows:

1. Dynamic silt monitoring/estimation [8]
2. Sensor Placement Optimization [19]
3. SSO mitigation – simple level sensor [4]
4. NRW – DMA [18]
5. Managing river/surface water quality [3]

APPENDIX D

Task 3 – Identify Available Sensor Technologies – Summary of Available Sensor Technologies

Designing Sensor Networks and Locations on an Urban Sewershed Scale

Task 3 – Identify Available Sensor Technologies – Summary of Available Sensor Technologies

PREPARED FOR:	Water Environment & Reuse Foundation
PREPARED BY:	CH2M
DATE:	January 29, 2018
PROJECT NUMBER:	SENG6R16

The approach for *Task 3 – Identify Available Sensor Technologies* of project SENG6R16 included a literature review, discussions with technology providers, evaluation of Task 1 survey results, review of case studies, and compilation of the results. Prior research conducted by the Water Environment and Reuse Foundation (WE&RF), the U.S. Environmental Protection Agency, and others was leveraged and built on to identify different groups of sensors available for use in urban sewershed networks. The suite of sensors extended beyond water quality and included other sensor types such as flow, level, and weather sensors. What was apparent based on the various investigations for this task was that the industry is still very much in its infancy with regard to urban sewershed monitoring that extends beyond the water resource recovery facilities (WRRFs) and pump stations. This Technical Memorandum summarizes the research findings.

Approach

Published literature was reviewed in the forms of journal articles, academic research, and industry reports to identify available sensor technologies. Additionally, technology providers were contacted for sensor information. The sections below summarize the literature review and information received from technology providers. Note that this is not an exhaustive review of individual sensors or sensor performance.

Literature Review

Flow, level, and water quality parameter sensor technologies are commercially available for wastewater and stormwater monitoring. These technologies are available for monitoring at the WRRF, in the sewershed network, and in the receiving streams. However, due to the complexities and unique challenges faced by municipal wastewater and stormwater utilities, identifying a single strategy for monitoring is not realistic.

WE&RF published two reports: 1) “Sensor Integration and Guidance: State of Knowledge” (2011) and

2) “Compendium of Sensors and Monitors and Their Use in the Global Water Industry” (2014). Both reports discuss the use of sensors for monitoring in drinking water and wastewater, and note in 2014, “over 250 manufacturers provide instruments for the automated, online measurement of well over 100 quality parameters” (WE&RF, 2014). Although some additional sensor technologies have been added since 2014, the basic functionality for sensor technologies has remained essentially the same and continues to be widely commercially available.

A review of online monitoring of wastewater quality included water quality parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC) as well as biosensors, optical sensors, and sensor arrays (Bourgeois, et al., 2001). A more recent review included “modern in-situ methods for real-time wastewater quality monitoring” (Korostynska, et al., 2013). However, both reviews focused primarily on wastewater quality and detecting pollutants in wastewater. There was little to no assessment of other factors such as monitoring level or flow, which have been shown to be important monitoring parameters for wastewater and stormwater.

Another study evaluated “the combined sewer system of the urban area of the city of Pau (south-west France)” and included “four tipping-bucket rain gauges, seven flow meters in the mains parts of the network and 27 CSOs” (Bersinger, 2015). Additionally, turbidity and conductivity were measured at one site. Data from 2009 to 2012 were assessed, and the researchers found online monitoring a “useful tool to manage wastewater treatment.”

Advances in academic research, including micro-sensors and biosensor technologies, have yet to become commercially or practically available. However, utilities can leverage the work being done by academic institutions participating in successful partnerships. The work being performed at the Metropolitan Sewer District of Greater Cincinnati (MSDGC) is one of the most advanced efforts in the development of an integrated sewershed monitoring program. The project is highlighted in a case study that can be located in the technical memorandum for Task 1 – Summary of Case Studies. MSDGC is managing its sewershed in a holistic manner and integrating sensors, models, and WRRFs to optimize the use of system facilities to reduce overflow incidents during wet-weather periods.

Interest among wastewater utilities in wastewater and stormwater sewershed network monitoring is evident. However, results from Task 1 indicate most utilities monitor level and flow, and few monitor sewershed water quality. Of the 20 utilities surveyed, only nine provided responses to questions regarding the use of water quality monitoring and the top parameters monitored (pH, total suspended solids [TSS], and conductivity). A majority of wastewater utilities indicated monitoring occurred primarily at the WRRF, with few monitoring in the sewershed network and even fewer monitoring receiving waters. However, case study results indicated there is interest in monitoring water quality parameters in the future.

Technology Providers

Information received from technology providers is summarized in Table 1, which lists the technology providers who responded to the survey requests and the sensors provided.

Table 1. List of Technology Providers.

Company	Sensors Provided	Technology Available	Applications
Trimble	• Level • Pressure • Rain gauge	• Strain gauge pressure sensor • Tipping bucket rain gauge pulse recorder	• Wastewater • Stormwater • Drinking Water
PMA Ltd.	• Tytronics Sentinel (multi-parameter)	• Colorimeter or titrator (alkalinity, ammonia, cyanide, iron, nitrates, phosphate, zinc)	• Wastewater • Drinking Water
Flowline Systems Ltd.	• Flow	• Ultrasonic flow meter • Electromagnetic flow meter • Differential pressure flow meter • Thermal mass flow meter	• Wastewater • Stormwater • Drinking water
Xylem Inc.	• Level • Flow •	• Hydrostatic level transmitter (piezoresistive) • Electromagnetic flow meter	• Wastewater • Stormwater • Drinking Water
s::can Measuring Systems, LLC	• Water quality parameters	• Spectrometry (BOD, COD, benzene, toluene, and xylene [BTX], TOC, dissolved organic carbon, ultraviolet [UV] 254, NO_3-N, NO_2-N, TSS, turbidity, color, temperature, 0_3, H_2S, assimilable organic carbon [AOC]) • Ion selective electrode (NH_4-N)	• Wastewater • Stormwater • Drinking Water
Hach	• Level (sludge) • Water quality parameters	• Ultrasonic level sensor • Luminescence (dissolved oxygen) • Spectrometry (TOC, UV, TSS) • Photometric (phosphorous) • Gas selective electrode or ion selective electrode (NH_4-N)	• Wastewater • Stormwater • Drinking Water

The sensors listed in Table 1 do not include communication devices, such as remote telemetry units, or proprietary software packages. Additionally, many of the above technology providers have water quality sensors for drinking water applications but are not recommended for wastewater or stormwater.

Appendix C, "Online Water Quality Sensors and Monitors Manufacturers," of WE&RF's *Compendium of Sensors and Monitors and Their Use in the Global Water Industry* (2014) provides a more complete list of available water quality sensor and monitor manufacturers. More updated information from individual technology providers can be found on their websites.

Summary

Although there are sensor technologies available for monitoring urban sewersheds, the sensor review found that many utilities monitor at the WRRFs or pump stations and not necessarily in the sewershed. The suite of sensors commercially available extends beyond water quality and includes other sensor types, such as flow, level, and weather sensors. What was apparent during the various investigations for this task is that the industry is still very much in its infancy with regard to urban sewershed monitoring that extends beyond the WRRFs and pump stations.

However, during review of available technologies, technology providers were found that are receptive to utility feedback and have begun providing support for water recycling and reuse.

References

WE&RF. 2010. Sensor Integration and Guidance: State of the Knowledge. Alexandria, VA. http://www.werf.org/i/ka/Sensors/a/ka/Sensors.aspx

WE&RF. 2014. Compendium of Sensors and Monitors and Their Use in the Global Water Industry. Alexandria, VA. http://www.werf.org/i/ka/Sensors/a/ka/Sensors.aspx

Bourgeois, W., J. Burgess, and R. Stuetz. 2001. On-line monitoring of wastewater quality: a review. *Journal of Chemical Technology and Biotechnology,* 76:337-348.

Korostynska O., A. Mason, A.I. Al-Shamma'a. 2013. "Monitoring Pollutants in Wastewater: Traditional Lab Based versus Modern Real-Time Approaches." In *Smart Sensors for Real-Time Water Quality Monitoring*, edited by Subhas C. Mukhopadhyay and Alex Mason. Smart Sensors, Measurement and Instrumentation, Vol 4. Springer-Verlag Berlin Heidelberg. http://www.springer.com/us/book/9783642370052.

Bersinger, T., I. Le Hécho, G. Bareille, T. Pigot, and A. Lecomte. 2015. Continuous Monitoring of Turbidity and Conductivity in Wastewater Networks: An Easy Tool to Assess the Pollution Load Discharged into Receiving Water. *Journal of Water Science*, *28*(1), 9-17. http://id.erudit.org/iderudit/1030002ar

APPENDIX E

Task 4 – Develop Use Cases – Summary of Use Cases

Designing Sensor Networks and Locations on an Urban Sewershed Scale

Task 4 – Development of Use Cases

PREPARED FOR:	Water Environment & Reuse Foundation
PREPARED BY:	CH2M
DATE:	January 31, 2018
PROJECT NUMBER:	SENG6R16

The plan for *Task 4 – Develop Use Cases* for project SENG6R16 involved using the information gained during Tasks 1 through 3 to identify the top use cases that address the most significant challenges in urban sewersheds by the use of advanced sensor networks. These would be a combination of successful case studies that have been implemented by utilities and new cases that can be considered for a Phase II project, being an extension of the work performed in this project (SENG6R16) and project SENG7R16 "Leveraging Other Industries – Big Data Management." This Technical Memorandum provides a summary of the challenges identified in previous tasks and recommended use cases that could be the focus of the Phase II project.

Approach

Survey results and case studies provided by utilities and technology providers, along with information from the expert workshop, were reviewed to summarize the challenges identified. These challenges are summarized below with use cases to address the most significant challenges identified.

Challenges Identified

The main challenges identified in the survey results provided by utilities were as follows:

1. Capacity issues including inflow and infiltration (I&I)
2. Asset management
3. Pump station upgrades and improvements

The main challenges identified in the survey results provided by technology providers were as follows:

1. Capacity issues
2. Combined sewer overflows (CSOs)
3. Aging infrastructure

The main challenges identified in the case studies provided by utilities and technology providers were as follows:

- Sanitary sewer overflows (SSOs)

- CSOs
- Capacity issues including I&I
- Aging infrastructure
- Updating sewershed models with survey data and as-built data to provide better accuracy
- Security concerns with the use of remote communications
- Reliability of telephone communication methods for remote lift/meter stations to supervisory control and data acquisition (SCADA) system at water resource recovery facilities (WRRFs)
- Existing infrastructure condition assessment and capacity assurance due to growth and changes in water conservation trends
- Obtaining timely high-water-level alerts at critical locations of the conveyance systems
- Staff training and development
- Consent decrees

Aging infrastructure was identified by technology providers in their survey responses as a main challenge, but it was not included on the survey questions for utilities. However, the results from the case studies indicate utilities also indicate aging infrastructure as a main challenge.

The top 10 use cases identified at the expert workshop were as follows:

1. Correlation between weather events and operational data to identify and predict overflow events
2. More efficient asset management and failure prediction
3. Identification and prediction of nitrification within chloraminated systems
4. Real-time modeling driven with real-time sensor data
5. Advanced analytics for source water protection
6. Dynamic silt monitoring and estimation within pipelines
7. Tools for optimization of sensor placement within the sewershed
8. SSO mitigation using simple level sensors
9. Identification and management of non-revenue water (NRW) in distribution systems
10. Management of river/surface water quality

Some participants at the expert workshop, who were from water/wastewater utilities, included drinking water-related use cases. As such, use case numbers 3, 5, and 9 are representative of use cases for drinking water utilities. These are, therefore, not considered challenges for wastewater utilities.

The survey results also showed that, while many utilities monitor water quality parameters at the WWTP, these parameters are not often monitored in the sewershed network due to perceived cost and reliability issues. However, monitoring water quality parameters in the sewershed network can be beneficial. For example, water quality parameters can be used to determine when to release stored wastewater and stormwater. Selecting the stored wastewater or stormwater with lower levels of BOD, COD, and TSS first for release can reduce environmental impact.

Monitoring water quality parameters can also be used to quantify biological loadings of wastewater from specific connections. The data received can be used by regional WWTPs to apportion processing costs based on WRRF loadings (BOD and TSS) as well as hydraulic capacity.

Potential Phase II Use Cases Identified

Based on the challenges identified in the preceding section, the following four use cases have been developed for inclusion in the Phase II project:

- **Use Case No. 1:** Managing dry weather (SSO) and wet weather (CSO) overflows through data correlation and enhanced operational practices.

  One common theme that was captured in a number of the suggested use cases referred to overflows; both CSOs and SSOs, and the correlation between multiple data sets and overflow incidents. This use case could be separated into two use cases: (a) SSO dry weather overflows and (b) CSO wet weather overflows.

- **Use Case No. 2:** Developing video analytics for different types of pipeline materials to rapidly identify problems that lead to I&I.

  Identification of points of I&I into sewer systems is a critical problem for both sanitary and combined sewer systems. This impact includes overflows, energy associated with additional pumping costs, and energy and treatment costs associated with additional flows into the WWTP. Identifying problems in sanitary and combined sewer systems using video cameras can be a costly and time-intensive process.

- **Use Case No. 3:** Evaluating water quality in the sewer, and using the results for decision-making to reduce the environmental impact of CSOs.

  Evaluating the impact of diluted CSOs into surface waters could significantly reduce impacts to downstream treatment operations, construction of large capital projects, and energy costs of pumping larger quantities of water downstream.

- **Use Case No. 4:** Monitoring for conditions that might cause pipe corrosion (e.g., H_2S levels) and control chemical feed.

Summary

Based on the results of the surveys, case studies provided, and the expert workshop, four use cases have been identified as follows:

- **Use Case No. 1:** Managing dry weather (SSO) and wet weather (CSO) overflows through data correlation and enhanced operational practices.
- **Use Case No. 2:** Developing video analytics for different types of pipeline materials to rapidly identify problems that lead to I&I.
- **Use Case No. 3:** Evaluating water quality to reduce the environmental impact of CSOs.
- **Use Case No. 4:** Monitoring for conditions that might cause pipe corrosion (e.g., H_2S levels) and control chemical feed.

It is recommended that the Phase II Demonstration project include two of these use cases.

References

Bersinger, T., I. Le Hécho, G. Bareille, T. Pigot, and A. Lecomte. 2015. "Continuous Monitoring of Turbidity and Conductivity in Wastewater Networks: An Easy Tool to Assess the Pollution Load Discharged into Receiving Water." Journal of Water Science 28(1), 9-17. http://id.erudit.org/iderudit/1030002ar

Bourgeois, W., J. Burgess, and R. Stuetz. 2001. "On-line monitoring of wastewater quality: a review." Journal of Chemical Technology and Biotechnology 76:337-348.

Korostynska O., A. Mason, and A.I. Al-Shamma'a. 2013. "Monitoring Pollutants in Wastewater: Traditional Lab Based versus Modern Real-Time Approaches." In *Smart Sensors for Real-Time Water Quality Monitoring*, edited by Subhas C. Mukhopadhyay and Alex Mason. Smart Sensors, Measurement and Instrumentation, Vol 4. Springer-Verlag Berlin Heidelberg. http://www.springer.com/us/book/9783642370052.

WE&RF. 2010. "Sensor Integration and Guidance: State of the Knowledge." Alexandria, VA. http://www.werf.org/i/ka/Sensors/a/ka/Sensors.aspx .

WE&RF. 2014. "Compendium of Sensors and Monitors and Their Use in the Global Water Industry." Alexandria, VA. http://www.werf.org/i/ka/Sensors/a/ka/Sensors.aspx.

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